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Guide for the Use of the International System of Units (SI)

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Ambler Thompson and Barry N. Taylor

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Preface

The International System of Units, universally abbreviated SI (from the French *Le Système International d'Unités*), is the modern metric system of measurement. Long the dominant measurement system used in science, the SI is becoming the dominant measurement system used in international commerce.

The Omnibus Trade and Competitiveness Act of August 1988 [Public Law (PL) 100-418] changed the name of the National Bureau of Standards (NBS) to the National Institute of Standards and Technology (NIST) and gave to NIST the added task of helping U.S. industry increase its competitiveness in the global marketplace. It also recognized the rapidly expanding use of the SI by amending the Metric Conversion Act of 1975 (PL 94-168). In particular, section 5164 (Metric Usage) of PL 100-418 designates

> the metric system of measurement as the preferred system of weights and measures for United States trade and commerce . . .

and requires that

> each Federal agency, by a date certain and to the extent economically feasible by the end of fiscal year 1992, use the metric system of measurement in its procurements, grants, and other business-related activities, except to the extent that such use is impractical or is likely to cause significant inefficiencies or loss of markets for United States firms . . .

In January 1991, the Department of Commerce issued an addition to the Code of Federal Regulations entitled "Metric Conversion Policy for Federal Agencies," 15 CFR 1170, which removes the voluntary aspect of the conversion to the SI for Federal agencies and gives in detail the policy for that conversion. Executive Order 12770, issued in July 1991, reinforces that policy by providing Presidential authority and direction for the use of the metric system of measurement by Federal agencies and departments.*

The Metric Act of 1866 allowed use of the metric system of measurement in the United States. In 2007, the 1866 law was amended by PL 110–69, also known as the America COMPETES Act. This amendment updated the definition of the metric system:

> "The metric system of measurement shall be defined as the International System of Units as established in 1960, and subsequently maintained, by the General Conference of Weights and Measures, and as interpreted or modified for the United States by the Secretary of Commerce."

The America COMPETES Act also repealed separate legislation on electrical and photometric units, as they are included in SI, and it established UTC (Coordinated Universal Time) as the basis for standard time in the United States.

Because of the importance of the SI to both science and technology, NIST has over the years published documents to assist NIST authors and other users of the SI, especially to inform them of changes in the SI and in SI usage. For example, this third edition of the *Guide* replaces the second edition (1995) prepared by Barry N. Taylor, which replaced the first edition (1991) prepared by Arthur O. McCoubrey. That edition, in turn, replaced NBS Letter Circular LC 1120 (1979), which was widely distributed in the United States and which was incorporated into the *NBS Communications Manual for Scientific, Technical, and Public Information*, a manual of instructions issued in 1980 for the preparation of technical publications at NBS.

* Executive Order 12770 was published in the *Federal Register*, Vol. 56, No. 145, p. 35801, July 29, 1991; 15 CFR 1170 was originally published in the *Federal Register*, Vol. 56, No. 1, p. 160, January 2, 1991, as 15 CFR Part 19, but was redesignated 15 CFR 1170.

It is quite natural for NIST to publish documents on the use of the SI. First, NIST coordinates the Federal Government policy on the conversion to the SI by Federal agencies and on the use of the SI by U.S. industry and the public. Second, NIST provides official U.S. representation in the various international bodies established by the Meter Convention (*Convention du Mètre*, often called the Treaty of the Meter in the United States), which was signed in Paris in 1875 by seventeen countries, including the United States (51 countries are now members of the Convention).

One body created by the Meter Convention is the General Conference on Weights and Measures (CGPM, *Conférence Générale des Poids et Mesures*), a formal diplomatic organization.** The International System was in fact established by the 11th CGPM in 1960, and it is the responsibility of the CGPM to ensure that the SI is widely disseminated and that it reflects the latest advances in science and technology.

This 2008 edition of the *Guide* corrects a small number of misprints in the 1995 edition, incorporates the modifications made to the SI by the CGPM and CIPM in the last 13 years, and updates the bibliography. Some minor changes in format have also been made in an attempt to improve the ease of use of the *Guide*.

In keeping with U.S. and International practice (see Sec. C.2), this *Guide* uses the dot on the line as the decimal marker. In addition this *Guide* utilizes the American spellings "meter," "liter," and "deka" rather than "metre," "litre," and "deca," and the name "metric ton" rather than "tonne."

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** See Ref. [1] or [2] for a brief description of the various bodies established by the Meter Convention: The International Bureau of Weights and Measures (BIPM, *Bureau International des Poids et Mesures*), the International Committee for Weights and Measures (CIPM, *Comité International des Poids et Mesures*), and the CGPM. The BIPM, which is located in Sèvres, a suburb of Paris, France, and which has the task of ensuring worldwide unification of physical measurements, operates under the exclusive supervision of the CIPM, which itself comes under the authority of the CGPM. In addition to a complete description of the SI, Refs. [1] and [2] also give the various CGPM and CIPM resolutions on which it is based.

Check List for Reviewing Manuscripts

The following check list is intended to help NIST authors review the conformity of their manuscripts with proper SI usage and the basic principles concerning quantities and units. (The chapter or section numbers in parentheses indicate where additional information may be found.)

(1) ☐ Only SI units and those units recognized for use with the SI are used to express the values of quantities. Equivalent values in other units are given in parentheses following values in acceptable units *only* when deemed necessary for the intended audience. (See Chapter 2.)

(2) ☐ Abbreviations such as sec (for either s or second), cc (for either cm^3 or cubic centimeter), or mps (for either m/s or meter per second), are avoided and only standard unit symbols, SI prefix symbols, unit names, and SI prefix names are used. (See Sec. 6.1.8.)

(3) ☐ The combinations of letters "ppm," "ppb," and "ppt," and the terms part per million, part per billion, and part per trillion, and the like, are not used to express the values of quantities. The following forms, for example, are used instead: 2.0 µL/L or $2.0 \times 10^{-6}\ V$, 4.3 nm/m or $4.3 \times 10^{-9}\ l$, 7 ps/s or $7 \times 10^{-12}\ t$, where V, l, and t are, respectively, the quantity symbols for volume, length, and time. (See Sec. 7.10.3.)

(4) ☐ Unit symbols (or names) are not modified by the addition of subscripts or other information. The following forms, for example, are used instead. (See Secs. 7.4 and 7.10.2.)

$V_{\mathrm{max}} = 1000$ V	*but not*:	$V = 1000\ \mathrm{V_{max}}$
a mass fraction of 10 %	*but not*:	10 % (*m*/*m*) or 10 % (by weight)

(5) ☐ Statements such as "the length l_1 exceeds the length l_2 by 0.2 %" are avoided because it is recognized that the symbol % represents simply the number 0.01. Instead, forms such as "$l_1 = l_2\ (1 + 0.2\ \%)$" or "$\Delta = 0.2\ \%$" are used, where Δ is defined by the relation $\Delta = (l_1 - l_2)/l_2$. (See Sec. 7.10.2.)

(6) ☐ Information is not mixed with unit symbols (or names). For example, the form "the water content is 20 mL/kg" is used and not "20 mL H_2O/kg" or "20 mL of water/kg." (See Sec. 7.5.)

(7) ☐ It is clear to which unit symbol a numerical value belongs and which mathematical operation applies to the value of a quantity because forms such as the following are used. (See Sec. 7.7.)

35 cm × 48 cm	*but not*:	35 × 48 cm
1MHz to 10 MHz or (1 to 10) MHz	*but not*:	1 MHz – 10 MHz or 1 to 10 MHz
20 °C to 30 °C or (20 to 30) °C	*but not*:	20 °C – 30 °C or 20 to 30 °C
123 g ± 2 g or (123 ± 2) g	*but not*:	123 ± 2 g
70 % ± 5 % or (70 ± 5) %	*but not*:	70 ± 5 %
240 × (1 ± 10 %) V	*but not*:	240 V ± 10 % (one cannot add 240 V and 10 %)

(8) ☐ Unit symbols and unit names are not mixed and mathematical operations are not applied to unit names. For example, only forms such as $\mathrm{kg/m^3}$, $\mathrm{kg \cdot m^{-3}}$, or kilogram per cubic meter are used and *not* forms such as kilogram/m^3, kg/cubic meter, kilogram/cubic meter, kg per m^3, or kilogram per meter^3. (See Secs. 6.1.7, 9.5, and 9.8.)

(9) ☐ Values of quantities are expressed in acceptable units using Arabic numerals and the symbols for the units. (See Sec. 7.6.)

$m = 5$ kg	*but not*:	m = five kilograms or m = five kg
the current was 15 A	*but not*:	the current was 15 amperes.

(10) ☐ There is a space between the numerical value and unit symbol, even when the value is used as an adjective, except in the case of superscript units for plane angle. (See Sec. 7.2.)

a 25 kg sphere	*but not*:	a 25-kg sphere
an angle of 2°3'4"	*but not:*	an angle of 2 °3 '4 "

If the spelled-out name of a unit is used, the normal rules of English are applied: "a roll of 35-millimeter film." (See Sec. 7.6, note 3.)

(11) ☐ The digits of numerical values having more than four digits on either side of the decimal marker are separated into groups of three using a thin, fixed space counting from both the left and right of the decimal marker. For example, 15 739.012 53 is highly preferred to 15739.01253. Commas are not used to separate digits into groups of three. (See Sec. 10.5.3.)

(12) ☐ Equations between quantities are used in preference to equations between numerical values, and symbols representing numerical values are different from symbols representing the corresponding quantities. When a numerical-value equation is used, it is properly written and the corresponding quantity equation is given where possible. (See Sec. 7.11.)

(13) ☐ Standardized quantity symbols such as those given in Refs. [4] and [5] are used, for example, R for resistance and A_r for relative atomic mass, and not words, acronyms, or ad hoc groups of letters. Similarly, standardized mathematical signs and symbols such as are given in Ref. [4: ISO 31-11] are used, for example, "tan x" and not "tg x." More specifically, the base of "log" in equations is specified when required by writing $\log_a x$ (meaning log to the base a of x), lb x (meaning $\log_2 x$), ln x (meaning $\log_\mathrm{e} x$), or lg x (meaning $\log_{10} x$). (See Secs. 10.1.1 and 10.1.2.)

(14) ☐ Unit symbols are in roman type, and quantity symbols are in italic type with superscripts and subscripts in roman or italic type as appropriate. (See Sec. 10.2 and Secs. 10.2.1 to 10.2.4.)

(15) ☐ When the word "weight" is used, the intended meaning is clear. (In science and technology, weight is a force, for which the SI unit is the newton; in commerce and everyday use, weight is usually a synonym for mass, for which the SI unit is the kilogram.) (See Sec. 8.3.)

(16) ☐ A quotient quantity, for example, mass density, is written "mass divided by volume" rather than "mass per unit volume." (See Sec. 7.12.)

(17) ☐ An object and any quantity describing the object are distinguished. (Note the difference between "surface" and "area," "body" and "mass," "resistor" and "resistance," "coil" and "inductance.") (See Sec. 7.13.)

(18) ☐ The obsolete term normality and the symbol N, and the obsolete term molarity and the symbol M, are not used, but the quantity amount-of-substance concentration of B (more commonly called concentration of B), and its symbol c_B and SI unit mol/m^3 (or a related acceptable unit), are used instead. Similarly, the obsolete term molal and the symbol m are not used, but the quantity molality of solute B, and its symbol b_B or m_B and SI unit mol/kg (or a related SI unit), are used instead. (See Secs. 8.6.5 and 8.6.8.)

Contents

1 Introduction

1.1 Purpose of *Guide*

The International System of Units was established in 1960 by the 11th General Conference on Weights and Measures (CGPM— see Preface). Universally abbreviated SI (from the French *Le Système International d'Unités*), it is the modern metric system of measurement used throughout the world. This *Guide* has been prepared by the National Institute of Standards and Technology (NIST) to assist members of the NIST staff, as well as others who may have need of such assistance, in the use of the SI in their work, including the reporting of results of measurements.

1.2 Outline of *Guide*

The Preface gives the principal Federal Government actions taken since 1988 regarding the SI and introduces the international body— the CGPM—that is responsible for the SI.

A check list immediately follows the Preface to help NIST authors review the conformity of their manuscripts with proper SI usage and the basic principles concerning quantities and units.

A detailed Contents, the aim of which is to simplify the use of the *Guide*, follows the check list.

This introductory chapter gives the purpose of the *Guide* and its outline, while Chapter 2 summarizes and clarifies the NIST policy on the use of the SI in NIST publications.

Chapter 3 notes the existence of a number of publications on the SI and gives the two organizational units at NIST to which questions concerning the SI may be directed and from which additional information about the SI may be obtained.

Chapter 4 discusses the fundamental aspects of the SI, including the two current classes of SI units: base, and derived; those derived units that have special names and symbols, including the degree Celsius; and the SI prefixes that are used to form decimal multiples and submultiples of units.

Chapter 5 discusses units that are outside the SI and indicates those that may be used with it and those that may not. It also gives (see Sec. 5.4) precise definitions of the terms "SI units" and "acceptable units" as used in this *Guide*.

Chapter 6 gives the rules and style conventions for printing and using units, especially unit symbols and SI prefix symbols.

Chapters 7 and 8, which some readers may view as the most important parts of this *Guide*, provide, respectively, the rules and style conventions for expressing the values of quantities, and clarifying comments on some often troublesome quantities and their units.

Chapter 9 gives the rules and style conventions for spelling unit names.

Chapter 10 further elaborates on printing and using symbols and numbers in scientific and technical documents and is intended to assist NIST authors prepare manuscripts that are consistent with accepted typesetting practice.

Appendix A gives the definitions of the SI base units, while Appendix B gives conversion factors for converting values of quantities expressed in units that are mainly unacceptable for use with the SI to values expressed mainly in SI units. Appendix B also includes a simplified discussion of rounding numbers and rounding converted numerical values of quantities. Appendix C discusses in some detail most of the references included in Appendix D—Bibliography, which concludes the *Guide*.

2 NIST Policy on the Use of the SI

In accordance with various Federal Acts, the Code of Federal Regulations, and Executive Order 12770 (see Preface), it is NIST policy that the SI shall be used in all NIST publications.[1] When the field of application or the special needs of users of NIST publications require the use of other units, the values of quantities shall first be expressed in acceptable units, where it is to be understood that acceptable units include the SI units and those units recognized for use with the SI; the corresponding values expressed in the other units shall then follow in parentheses. (For precise definitions of the terms "SI units" and "acceptable units" as used in this *Guide*, see Sec. 5.4.) Exceptions to this policy require the prior approval of the NIST Director. The following three sections—2.1 Essential data, 2.1.1 Tables and graphs, and 2.2 Descriptive information—elaborate upon this policy.

2.1 Essential data

Essential data express or interpret quantitative results. All such data shall be given in acceptable units. In those cases where

— the sole use of acceptable units would compromise good communication, or
— units other than acceptable units have been specified as a contractual requirement,

values of quantities shall be given in acceptable units followed, in parentheses, by the values of the same quantities given in the other units.

Exceptions may sometimes be necessary for commercial devices, technical standards, or quantities having special legal significance; examples include commercial weights and measures devices and the related laws and regulations. However, even in such cases, values of quantities expressed in acceptable units should be used when possible with the same values expressed in other units following in parentheses.

2.1.1 Tables and graphs

In tables, values of quantities expressed in acceptable units and the corresponding values expressed in other units may be shown in parallel columns, with the acceptable-unit column preceding the other-unit column. In graphs, axes labeled in other units shall be given secondary status. This may preferably be done by placing scale marks on and labeling the left-hand ordinate and bottom abscissa in acceptable units, and placing scale marks on and labeling the right-hand ordinate and top abscissa in other units. Alternatively, lighter-weight scale marks and smaller type may be employed to indicate other units using the same ordinate and abscissa as is used for the acceptable units.

2.2 Descriptive information

Descriptive information characterizes arrangements, environments, the generalized dimensions of objects, apparatus, or materials, and other attributes that do not enter directly into calculations or results. When necessary for effective communication, such information may be expressed using customary terms that are widely used and recognized. Examples include common drill sizes and traditional tools used in the United States, U.S. standard fastener sizes, commercial pipe sizes, and other common terms used in the trades, the professions, the marketplace, sports, and various social activities. When such descriptive information is given, values in acceptable units are not required. For example, it is permissible to refer to a "36-inch pipeline" or a "half-inch drill" without first giving the value in an acceptable unit.

[1] The NIST policy on the use of the SI is set forth in the NIST Administration Manual, Chapter 4, Communications, Subchapter 4.09, NIST Technical Communications Program, Appendix D—Use of Metric Units.

3 Other Sources of Information on the SI

3.1 Publications

Appendix C briefly describes a number of publications that deal with the SI and related topics; citations for these publications are given in Appendix D—Bibliography. Additional information about the SI is also available from the two NIST organizational units indicated in Secs. 3.2 and 3.3.

3.2 Fundamental Constants Data Center

Questions concerning the more fundamental aspects of the SI and subtle aspects of proper SI usage may be directed to:

Fundamental Constants Data Center
Physics Laboratory
National Institute of Standards and Technology
100 Bureau Drive, Stop 8420
Gaithersburg, MD 20899-8420

Telephone: (301) 975-3200
Fax: (301)-990-1350
SI Units Web Page: http://physics.nist.gov/cuu/Units/index.html

3.3 Metric Program

Questions concerning Federal Government use of the SI and Federal Government policy on the use of the SI by U.S. industry and the public may be directed to:

Metric Program
Technology Services
National Institute of Standards and Technology
100 Bureau Drive, Stop 2600
Gaithersburg, MD 20899-2600

Telephone: (301) 975-4004
Fax: (301) 975-8091
Email: TheSI@nist.gov
http://nist.gov/metric

4 The Two Classes of SI Units and the SI Prefixes

Since the 1995 edition of this *Guide*, the 20th CGPM, which met October 9 - 12, 1995, decided to eliminate the class of supplementary units as a separate unit class in the SI. The SI now consists of only two classes of units: base units and derived units. The radian and steradian, which were the two supplementary units, are now subsumed into the class of SI derived units. Thus the SI units are currently divided into base units and derived units, which together form what is called "the coherent system of SI units."[2] The SI also includes the prefixes to form decimal multiples and submultiples of SI units.

[2] According to Ref. [4: ISO 31-0], a system of units is coherent with respect to a system of quantities and equations if the system of units is chosen in such a way that the equations between numerical values have exactly the same form (including the numerical factors) as the corresponding equations between the quantities (see Secs. 7.11 and 7.14). In such a coherent system, of which the SI is an example, no numerical factor other than the number 1 ever occurs in the expressions for the derived units in terms of the base units.

4.1 SI base units

Table 1 gives the seven base quantities, assumed to be mutually independent, on which the SI is founded, and the names and symbols of their respective units, called "SI base units." Definitions of the SI base units are given in Appendix A. The kelvin and its symbol K are also used to express the value of a temperature interval or a temperature difference (see Sec. 8.5).

Table 1. SI base units

	SI base unit	
Base quantity	**Name**	**Symbol**
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

4.2 SI derived units

Derived units are expressed algebraically in terms of base units or other derived units. The symbols for derived units are obtained by means of the mathematical operations of multiplication and division. For example, the derived unit for the derived quantity molar mass (mass divided by amount of substance) is the kilogram per mole, symbol kg/mol. Additional examples of derived units expressed in terms of SI base units are given in Table 2. (The rules and style conventions for printing and using SI unit symbols are given in Secs. 6.1.1 to 6.1.8.)

Table 2. Examples of SI coherent derived units expressed in terms of SI base units

	SI coherent derived unit	
Derived quantity	**Name**	**Symbol**
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wavenumber	reciprocal meter	m^{-1}
density, mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
luminance	candela per square meter	cd/m^2
amount-of-substance concentration amount concentration , concentration	mole per cubic meter	mol/m^3

4.2.1 SI coherent derived units with special names and symbols

Certain SI coherent derived units have special names and symbols; these are given in Table 3. Consistent with the discussion in Sec. 4, the radian and steradian, which are the two former supplementary units, are included in Table 3. The last four units in Table 3 were introduced into the SI for reasons of safeguarding human health.

Table 3. The 22 SI coherent derived units with special names and symbols.

	SI coherent derived unit [(a)]			
	Special name	**Special symbol**	**Expression in terms of other SI units**	**Expression in terms of SI base units**
plane angle	radian [(b)]	rad	1 [(b)]	m/m
solid angle	steradian [(b)]	sr [(c)]	1 [(b)]	m^2/m^2
frequency	hertz [(d)]	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, amount of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, amount of electricity	coulomb	C		$s \cdot A$
electric potential difference[(e)], electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^{-2}$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius [(f)]	°C		K
luminous flux	lumen	lm	$cd \cdot sr$[(c)]	Cd
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd$
activity referred to a radionuclide [(g)]	becquerel [(d)]	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert [(h)]	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$

(*a*) The SI prefixes may be used with any of the special names and symbols, but when this is done the resulting unit will no longer be coherent. (See Sec. 6.2.8.)
(*b*) The radian and steradian are special names for the number one that may be used to convey information about the quantity concerned. In practice the symbols rad and sr are used where appropriate, but the symbol for the derived unit one is generally omitted in specifying the values of dimensionless quantities. (See Sec 7.10.)
(*c*) In photometry the name steradian and the symbol sr are usually retained in expressions for units.
(*d*) The hertz is used only for periodic phenomena, and the becquerel is used only for stochastic processes in activity referred to a radionuclide.
(*e*) Electric potential difference is also called "voltage" in the United States.
(*f*) The degree Celsius is the special name for the kelvin used to express Celsius temperatures. The degree Celsius and the kelvin are equal in size, so that the numerical value of a temperature difference or temperature interval is the same when expressed in either degrees Celsius or in kelvins. (See Secs. 4.2.1.1 and 8.5.)
(*g*) Activity referred to a radionuclide is sometimes incorrectly called radioactivity.
(*h*) See Refs. [1, 2], on the use of the sievert.

4.2.1.1 Degree Celsius

In addition to the quantity thermodynamic temperature (symbol T), expressed in the unit kelvin, use is also made of the quantity Celsius temperature (symbol t) defined by the equation

$$t = T - T_{0,}$$

where T_0 = 273.15 K by definition. To express Celsius temperature, the unit degree Celsius, symbol °C, which is equal in magnitude to the unit kelvin, is used; in this case, "degree Celsius" is a special name used in place of "kelvin." An interval or difference of Celsius temperature, however, can be expressed in the unit kelvin as well as in the unit degree Celsius (see Sec. 8.5). (Note that the thermodynamic temperature T_0 is exactly 0.01 K below the thermodynamic temperature of the triple point of water (see Sec. A.6).)

4.2.2 Use of SI derived units with special names and symbols

Examples of SI derived units that can be expressed with the aid of SI derived units having special names and symbols are given in Table 4.

Table 4. Examples of SI coherent derived units expressed with the aid of SI derived units having special names and symbols.

Derived quantity	SI coherent derived unit		
	Name	**Symbol**	**Expression in terms of SI base units**
dynamic viscosity	pascal second	Pa · s	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton meter	N · m	$m^2 \cdot kg \cdot s^{-2}$
surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
angular velocity	radian per second	rad/s	$m \cdot m^{-1} \cdot s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
heat flux density, irradiance	watt per square meter	W/m^2	$kg \cdot s^{-3}$
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg · K)	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per meter kelvin	W(m · K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
energy density	joule per cubic meter	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
surface charge density	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
electric flux density, electric displacement	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
permittivity	farad per meter	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
permeability	henry per meter	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
molar entropy, molar heat capacity	joule per mole kelvin	J/(mol · K)	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and γ rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3} = m^2 \cdot kg \cdot s^{-3}$
radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3} = kg \cdot s^{-3}$
catalytic activity concentration	katal per cubic meter	kat/m^3	$m^{-3} \cdot s^{-1} \cdot mol$

The advantages of using the special names and symbols of SI derived units are apparent in Table 4. Consider, for example, the quantity molar entropy: the unit J/(mol · K) is obviously more easily understood than its SI base-unit equivalent, $m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$. Nevertheless, it should always be recognized that the special names and symbols exist for convenience; either the form in which special names or symbols are used for certain combinations of units or the form in which they are not used is correct. For example, because of the descriptive value implicit in the compound-unit form, communication is sometimes facilitated if magnetic flux (see Table 3) is expressed in terms of the volt second (V · s) instead of the weber (Wb) or the combination of SI base units, $m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$.

Tables 3 and 4 also show that the values of several different quantities are expressed in the same SI unit. For example, the joule per kelvin (J/K) is the SI unit for heat capacity as well as for entropy. Thus the name of the unit is not sufficient to define the quantity measured.

A derived unit can often be expressed in several different ways through the use of base units and derived units with special names. In practice, with certain quantities, preference is given to using certain units with special names, or combinations of units, to facilitate the distinction between quantities whose values have identical expressions in terms of SI base units. For example, the SI unit of frequency is specified as the hertz (Hz) rather than the reciprocal second (s^{-1}), and the SI unit of moment of force is specified as the newton meter (N · m) rather than the joule (J).

Similarly, in the field of ionizing radiation, the SI unit of activity is designated as the becquerel (Bq) rather than the reciprocal second (s^{-1}), and the SI units of absorbed dose and dose equivalent are designated as the gray (Gy) and the sievert (Sv), respectively, rather than the joule per kilogram (J/kg).

4.3 Decimal multiples and submultiples of SI units: SI prefixes

Table 5 gives the SI prefixes that are used to form decimal multiples and submultiples of units. They allow very large or very small numerical values (see Sec. 7.1) to be avoided. A prefix name attaches directly to the name of a unit, and a prefix symbol attaches directly to the symbol for a unit. For example, one kilometer, 1 km, is equal to one thousand meters, 1000 m or 10^3 m. When prefixes are used to form multiples and submultiples of SI base and derived units, the resulting units are no longer coherent. (See footnote 2 for a brief discussion of coherence.) The rules and style conventions for printing and using SI prefixes are given in Secs. 6.2.1 to 6.2.8. The special rule for forming decimal multiples and submultiples of the unit of mass is given in Sec. 6.2.7.

Table 5. SI prefixes

Factor	Prefix Name	Symbol	Factor	Prefix Name	Symbol
$10^{24} = (10^3)^8$	yotta	Y	10^{-1}	deci	d
$10^{21} = (10^3)^7$	zetta	Z	10^{-2}	centi	c
$10^{18} = (10^3)^6$	exa	E	$10^{-3} = (10^3)^{-1}$	milli	m
$10^{15} = (10^3)^5$	peta	P	$10^{-6} = (10^3)^{-2}$	micro	µ
$10^{12} = (10^3)^4$	tera	T	$10^{-9} = (10^3)^{-3}$	nano	n
$10^{9} = (10^3)^3$	giga	G	$10^{-12} = (10^3)^{-4}$	pico	p
$10^{6} = (10^3)^2$	mega	M	$10^{-15} = (10^3)^{-5}$	femto	f
$10^{3} = (10^3)^1$	kilo	k	$10^{-18} = (10^3)^{-6}$	atto	a
10^{2}	hecto	h	$10^{-21} = (10^3)^{-7}$	zepto	z
10^{1}	deka	da	$10^{-24} = (10^3)^{-8}$	yocto	y

Note: Alternative definitions of the SI prefixes and their symbols are not permitted. For example, it is unacceptable to use kilo (k) to represent 2^{10} = 1024, mega (M) to represent 2^{20} = 1 048 576, or giga (G) to represent 2^{30} = 1 073 741 824. See the note to Ref. [5] on page 74 for the prefixes for binary powers adopted by the IEC.

5 Units Outside the SI

Units that are outside the SI, that is, non-SI units, may be divided into three categories:

— those units that are accepted for use with the SI by the CIPM and hence this *Guide*;
— those units that are not accepted for use with the SI by the CIPM, but are temporarily accepted for use with the SI by this *Guide*; and
— those units that are not accepted for use with the SI by either the CIPM or this *Guide* and in the view of this *Guide* must strictly be avoided.

5.1 Units accepted for use with the SI

The following four sections discuss in detail the units this *Guide* accepts for use with the SI.

5.1.1 Hour, degree, liter, and the like

Certain units that are not part of the SI are essential and used so widely that they are accepted by the CIPM, and thus by this *Guide*, for use with the SI [2, 3]. These units are given in Table 6. The combination of units of this table with SI units to form derived units should be restricted to special cases in order not to lose the advantages of the coherence of SI units. (The use of SI prefixes with the units of Table 6 is discussed in Sec. 6.2.8.)

Additionally, this *Guide* recognizes that situations on occasion will require the use of time-related units other than those given in Table 6; such as using intervals of time be expressed in weeks, months, or years. In such cases, if a standardized symbol for the unit is not available, the name of the unit should be written out in full. (See Sec. 8.1 for a suggestion regarding the symbol for year and Chapter 9 for the rules and style conventions for spelling unit names.)

Table 6. Non-SI units accepted for use with the SI by the CIPM and this *Guide*

Name		Symbol	Value in SI units
minute	time	min	1 min = 60 s
hour	time	h	1 h = 60 min = 3600 s
day	time	d	1 d = 24 h = 86 400 s
degree	plane angle [(a)]	°	1° = (π/180) rad
minute	plane angle [(a)]	'	1' = (1/60)° = (π/10 800) rad
second	plane angle [(a)]	"	1" = (1/60)' = (π/648 000) rad
hectare[(h)]		ha	1ha = 1 hm^2 = 10^4 m^2
liter		L[(b)], l	1 L = 1 dm^3 = 10^{-3} m^3
metric ton [(c)]		T	1 t = 10^3 kg
neper		Np[(d,f)]	[see footnote (*g*) regarding the numerical value of logarythmic ratio quantities such as the neper, the bel, and the decibel]
bel		B[(e,f)]	
decibel		dB[(e,f)]	

(*a*) See also Sec. 7.2.

(*b*) The alternative symbol for the liter, L, was adopted by the CGPM in order to avoid the risk of confusion between the letter l and the number 1 (see Ref. [1] or [2]). Thus, although both l and L are internationally accepted symbols for the liter, to avoid this risk the symbol to be used in the United States is L (see Refs. [2] and [6]). The script letter ℓ is not an approved symbol for the liter.

(*c*) This is the name to be used for this unit in the United States (see Refs. [2] and [6]); it is also used in some other English-speaking countries. However, this unit is called "tonne" in Ref. [1] and is the name used in many countries.

(*d*) The statement LA = n Np (where n is a number) is interpreted to mean that $\ln(A_2 / A_1) = n$. Thus when L_A = 1 Np, A_2 / A_1 = e. The symbol A is used here to denote the amplitude of a sinusoidal signal, and L_A is then called the Napierian logarithmic amplitude ratio, or the Napierian amplitude level difference.

(*e*) The statement $L_X = m$ dB = (m / 10) B (where m is a number) is interpreted to mean that $\lg(X / X_0) = m/10$. Thus when L_X= 1 B, X / X_0 = 10, and when L_X= 1 dB, $X / X_0 = 10^{1/10}$. If X denotes a mean square signal or power-like quantity, L_X is called a power level referred to X_0. (See Sec. 8.7.)

(*f*) In using these units it is important that the nature of the quantity be specified, and that any reference value used be specified. These units are not SI units, but they have been accepted by the CIPM for use with the SI. For additional information on the neper and bel, see Ref. [5: IEC 60027-3], and Sec. 8.7 of this *Guide*.

(g) The numerical values of the neper, bel, and decibel (and hence the relation of the bel and the decibel to the neper) are rarely required. They depend on the way in which the logarithmic quantities are defined.

(h) This unit and its symbol are used to express agrarian area.

5.1.2 Electronvolt, astronomical unit, and unified atomic mass unit

The CIPM, and thus this *Guide*, accepts for use with the SI the units given in Table 7 [1, 2]. These units are used in specialized fields; their values in SI units must be obtained from experiment and, therefore, are not known exactly. (The use of SI prefixes with the units of Table 7 is discussed in Sec. 6.2.8.)

Table 7. Non-SI Units accepted for use with the SI by the CIPM and this *Guide*, whose values in SI units are obtained experimentally

Name	Symbol	Definition and Value in SI units
electronvolt	eV	(*a*)
astronomical unit	ua	(*b*)
unified atomic mass unit	u	(*c*)
dalton	Da	(d)

(*a*) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum, $1.602\,176\,487(40) \times 10^{-19}$ J. This value of 1 eV is the 2006 CODATA recommended value with the standard uncertainty in the last two digits given in parenthesis [19, 20].

(*b*) The astronomical unit is approximately equal to the mean Earth-Sun distance. It is the radius of an unperturbed circular Newtonian orbit about the Sun of a particle having infinitesimal mass, moving with a mean motion of 0.017 202 098 95 radians per day (known as the Gaussian constant). The value and standard uncertainty of the astronomical unit, ua, is $1.495\,978\,706\,91(6) \times 10^{11}$ m. This is cited from the IERS Conventions 2003 (D.D. McCarthy and G. Petit eds., IERS Technical Note 32, Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2004, 12). The value of the astronomical unit in meters comes from the JPL ephemerides DE403 (Standish E.M., Report of the IAU WGAS Sub-Group on Numerical Standards, Highlights of Astronomy, Appenzeller ed., Dordrecht: Kluwer Academic Publishers, 1995, 180-184).

(*c*) The unified atomic mass unit is equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state, $1.660\,538\,782(83) \times 10^{-27}$ kg. This value of 1 u is the 2006 CODATA recommended value with the standard uncertainty in the last two digits given in parenthesis [18, 19].

(*d*) The dalton (Da) and the unified atomic mass unit (u) are alternative names (and symbols) for the same unit, equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. The dalton is often combined with SI prefixes, for example to express the masses of large molecules in kilodaltons, kDa, or megadaltons, MDa.

Note: The abbreviation, AMU is not an acceptable unit symbol for the unified atomic mass unit. The only allowed name is "unified atomic mass unit" and the only allowed symbol is u.

5.1.3 Units from International Standards

There are a few highly specialized units that are given by the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC) and which in the view of this *Guide* are also acceptable for use with the SI. They include the octave, phon, and sone, and units used in information technology, including the baud (Bd), bit (bit), erlang (E), hartley (Hart), and shannon (Sh)[3]. It is the position of this *Guide* that the only such additional units NIST authors may use with the SI are those given in either the International Standards on quantities and units of ISO (Ref. [4]) or of IEC (Ref. [5]).

5.1.4 Natural and atomic units

In some cases, particularly in basic science, the values of quantities are expressed in terms of fundamental constants of nature. The two most important of these unit systems are the natural unit (n.u.) system used in high energy or particle physics, and the atomic unit (a.u.) system used in atomic physics and quantum chemistry. The use of these units with the SI is not formally accepted by the CIPM, but the CIPM recognizes their existence and importance. Therefore, this *Guide* formally accepts their use when it is necessary for effective communication. In such cases, the specific unit system used must be identified. Examples of physical quantities used as units are given in Table 8.

Table 8. Examples of physical quantities sometimes used as units

Kind of quantity	Physical quantity used as a unit	Symbol
speed	speed of light in vacuum (n.u.)	c
action	Planck constant divided by 2π (n.u.)	$\hbar$
mass	electron rest mass (n.u. and a.u.)	m_e
electric charge	elementary charge (a.u.)	e
length	Bohr radius (a.u.)	a_0
energy	Hartree energy (a.u.)	E_h
time	ratio of action to energy (a.u.)	$\hbar / E_h$

[3] The symbol in parentheses following the name of the unit is its internationally accepted unit symbol, but the octave, phon, and sone have no such unit symbols. For additional information on the neper and bel, see Ref. [5: IEC 60027-3], and Sec. 8.7 of this *Guide*.

5.2 Other Non-SI units accepted for use with the SI

Because of established practice in certain fields or countries, in 1978 the CIPM considered that it was permissible for the following units given in Table 9, nautical mile, knot, angstrom, are, barn, bar, and millimeter of mercury to continue to be used with the SI. However, these units must not be introduced in fields where they are not presently used. Further, this *Guide* strongly discourages the continued use of these units by NIST authors except when absolutely necessary. If these units are used by NIST authors the values of relevant quantities shall be given in terms of SI units first followed by these non-SI units in parentheses.

The curie, roentgen, rad, and rem have been added to the NIST SP 330 [2] and Table 9 of this *Guide*, since they are in wide use in the United States, especially in regulatory documents dealing with health and safety. Nevertheless, this *Guide* strongly discourages the continued use of the curie, roentgen, rad, and rem and recommends that SI units should be used by NIST authors only if necessary. If these units are used by NIST authors the values of relevant quantities shall be given in terms of SI units first followed by these outdated non-SI units in parentheses.

Table 9. Other non-SI units accepted for use with the SI either by the CIPM and this *Guide* (indicated by *), or by this *Guide* (indicated by **)

Name	Symbol	Value in SI units
nautical mile*		1 nautical mile = 1852 m
knot*		1 nautical mile per hour = (1852/3600) m/s
ångström*	Å	1 Å = 0.1 nm = 10^{-10} m
barn*	b	1 b = 100 fm^2 = 10^{-28} m^2
bar*	bar	1 bar = 0.1 MPa = 100 kPa = 1000 hPa = 10^5 Pa
millimeter of mercury*	mmHg	1 mmHg ≈ 133.322 Pa
curie**	Ci	1 Ci = 3.7 x 10^{10} Bq
roentgen**	R	1 R = 2.58 x 10^{-4} C/kg
rad**	rad$^{(a)}$	1 rad = 1 cGy = 10^{-2} Gy
rem**	rem	1 rem = 1 cSv = 10^{-2} Sv

(*a*) When there is risk of confusion with the symbol for the radian, rd may be used as the symbol for rad.

5.3 Units not accepted for use with the SI

The following two sections briefly discuss units not accepted for use with the SI.

5.3.1 CGS units

Table 10 gives examples of centimeter-gram-second (CGS) units having special names. These units are not accepted for use with the SI by this *Guide*. Further, no other units of the various CGS systems of units, which includes the CGS Electrostatic (ESU), CGS Electromagnetic (EMU), and CGS Gaussian systems, are accepted for use with the SI by this *Guide* except such units as the centimeter, gram, and second that are also defined in the SI.

Table 10. Examples of CGS units with special names (not accepted for use with the SI by this *Guide*)

Name	Symbol	Value in SI units
erg	erg	1 erg = 10^{-7} J
dyne	dyn	1 dyn = 10^{-5} N
poise[(a)]	P	1 P = 1 dyn · s/cm^2 = 0.1 Pa · s
stokes[(b)]	St	1 St = 1 cm^2/s = 10^{-4} m^2/s
gauss[(c)]	Gs, G	1 Gs corresponds to 10^{-4} T
oersted[(c)]	Oe	1 Oe corresponds to (1000/4π) A/m
maxwell[(c)]	Mx	1 Mx corresponds to 10^{-8} Wb
stilb	sb	1 sb = 1 cd/cm^2 = 10^4 cd/m^2
phot	ph	1 ph = 10^4 lx
gal[(d)]	Gal	1 Gal = 1 cm s^{-2} = 10^{-2} m s^{-2}

(*a*) The poise (P) is the CGS unit for viscosity (also called dynamic viscosity). The SI unit is the pascal second (Pa · s).
(*b*) The stokes (St) is the CGS unit for kinematic viscosity. The SI unit is the meter squared per second (m^2/s).
(*c*) This unit is part of the so-called electromagnetic three-dimensional CGS system and cannot strictly speaking be compared to the corresponding SI unit, which has four dimensions when only mechanical and electric quantities are considered.
(*d*) The gal is employed in geodesy and geophysics to express acceleration due to gravity.

5.3.2 Other unacceptable units

There are many units besides CGS units that are outside the SI and not accepted for use with it, including, of course, all of the U.S. customary (that is, inch-pound) units. In the view of this *Guide* such units must strictly be avoided and SI units, their multiples or submultiples, or those units accepted or temporarily accepted for use with the SI (including their appropriate multiples and submultiples), must be used instead. This restriction also applies to the use of unaccepted special names for SI units or special names for multiples or submultiples of SI units, such as mho for siemens (S) and micron for micrometer (μm). Table 11 gives a few examples of some of these other unacceptable units.

Table 11. Examples of other unacceptable units

Name	Symbol	Value in SI units
fermi	fermi	1 fermi = 1 fm = 10^{-15} m
photometric carat	metric carat	1 metric carat = 200 mg = 2 × 10^{-4} kg
torr	Torr	1 Torr = (101 325/760) Pa
standard atmosphere	atm	1 atm = 101 325 Pa
kilogram-force	kgf	1 kgf = 9.806 65 N
micron	μ	1 m = 1 μm = 10^{-6} m
calorie (various)	cal$_{th}$ (thermochemical)	1 cal$_{th}$ = 4.184 J
x unit	xu	1 xu ≈ 0.1002 pm = 1.002 × 10^{-13} m
stere	st	1 st = 1 m^3
gamma	γ	1 γ = 1 nT = 10^{-9} T
gamma (mass)	γ	1 γ = 1 μg = 10^{-9} kg
lambda (volume)	λ	1 λ = 1 μL = 10^{-6} L = 10^{-9} m^3

5.4 The terms "SI units" and "acceptable units"

Consistent with accepted practice [1, 2], this *Guide* uses either the term "SI units" or "units of the SI" to mean the SI base units and SI coherent derived units, and multiples and submultiples of these units formed by using the SI prefixes. The term "acceptable units," which is introduced in this *Guide* for convenience, is used to mean the SI units plus (a) those non-SI units accepted for use with the SI (see Tables 6 - 9); and (b) appropriate multiples and submultiples of such accepted non-SI units.

6 Rules and Style Conventions for Printing and Using Units

6.1 Rules and style conventions for unit symbols

The following eight sections give rules and style conventions related to the symbols for units.

6.1.1 Typeface

Unit symbols are printed in roman (upright) type regardless of the type used in the surrounding text. (See also Sec. 10.2 and Secs. 10.2.1 to 10.2.4.)

6.1.2 Capitalization

Unit symbols are printed in lower-case letters except that:

(a) the symbol or the first letter of the symbol is an upper-case letter when the name of the unit is derived from the name of a person; and

(b) the recommended symbol for the liter in the United States is L. (See Table 6, footnote (b).)

Examples:	m (meter)	s (second)	V (volt)
	Pa (pascal)	lm (lumen)	Wb (weber)

6.1.3 Plurals

Unit symbols are unaltered in the plural.

Example: $l = 75$ cm *but not*: $l = 75$ cms

Note: l is the quantity symbol for length. (The rules and style conventions for expressing the values of quantities are discussed in detail in Chapter 7.)

6.1.4 Punctuation

Unit symbols are not followed by a period unless at the end of a sentence.

Example: "Its length is 75 cm." or "It is 75 cm long." *but not*: "It is 75 cm. long."

6.1.5 Unit symbols obtained by multiplication

Symbols for units formed from other units by multiplication are indicated by means of either a half-high (that is, centered) dot or a space. However, this *Guide*, as does Ref. [6], prefers the half-high dot because it is less likely to lead to confusion.

Example: N · m or N m

Notes:

1. A half-high dot or space is usually imperative. For example, $\mathrm{m \cdot s^{-1}}$ is the symbol for the meter per second while ms−1 is the symbol for the reciprocal millisecond ($10^3\ \mathrm{s^{-1}}$— see Sec. 6.2.3).

2. Reference [4: ISO 31-0] suggests that if a space is used to indicate units formed by multiplication, the space may be omitted if it does not cause confusion. This possibility is reflected in the common practice of using the symbol kWh rather than kW · h or kW h for the kilowatt hour. Nevertheless, this Guide takes the position that a half-high dot or a space should always be used to

avoid possible confusion; for this same reason, only one of these two allowed forms should be used in any given manuscript.

6.1.6 Unit symbols obtained by division

Symbols for units formed from other units by division are indicated by means of a solidus (oblique stroke, /), a horizontal line, or negative exponents.

Example: m/s, $\frac{\mathrm{m}}{\mathrm{s}}$, or $\mathrm{m} \cdot \mathrm{s}^{-1}$

However, to avoid ambiguity, the solidus must not be repeated on the same line unless parentheses are used.

Examples: $\mathrm{m/s^2}$ or $\mathrm{m} \cdot \mathrm{s}^{-2}$ *but not*: m/s/s

$\mathrm{m} \cdot \mathrm{kg/(s^3} \cdot \mathrm{A)}$ or $\mathrm{m} \cdot \mathrm{kg} \cdot \mathrm{s}^{-3} \cdot \mathrm{A}^{-1}$ *but not*: $\mathrm{m} \cdot \mathrm{kg/s^3/A}$

Negative exponents should be used in complicated cases.

6.1.7 Unacceptability of unit symbols and unit names together

Unit symbols and unit names are not used together. (See also Secs. 9.5 and 9.8.)

Example: C/kg, $\mathrm{C} \cdot \mathrm{kg}^{-1}$, or coulomb per kilogram *but not*: coulomb/kg; coulomb per kg; C/kilogram; coulomb $\cdot$ kg^{-1}; C per kg; coulomb/kilogram

6.1.8 Unacceptability of abbreviations for units

Because acceptable units generally have internationally recognized symbols and names, it is not permissible to use abbreviations for their unit symbols or names, such as sec (for either s or second), sq. mm (for either mm^2 or square millimeter), cc (for either cm^3 or cubic centimeter), mins (for either min or minutes), hrs (for either h or hours), lit (for either L or liter), amps (for either A or amperes), AMU (for either u or unified atomic mass unit), or mps (for either m/s or meter per second). Although the values of quantities are normally expressed using symbols for numbers and symbols for units (see Sec. 7.6), if for some reason the name of a unit is more appropriate than the unit symbol (see Sec. 7.6, note 3), the name of the unit should be spelled out in full.

6.2 Rules and style conventions for SI prefixes

The following eight sections give rules and style conventions related to the SI prefixes.

6.2.1 Typeface and spacing

Prefix names and symbols are printed in roman (upright) type regardless of the type used in the surrounding text, and are attached to unit symbols without a space between the prefix name or symbol and the unit name or symbol. This last rule also applies to prefixes attached to unit names.

Examples: mL (milliliter) pm (picometer) GΩ (gigaohm) THz (terahertz)

6.2.2 Capitalization

The prefix symbols Y (yotta), Z (zetta), E (exa), P (peta), T (tera), G (giga), and M (mega) are printed in upper-case letters while all other prefix symbols are printed in lower-case letters (see Table 5). Prefix names are normally printed in lowercase letters.

6.2.3 Inseparability of prefix and unit

The grouping formed by a prefix symbol attached to a unit symbol constitutes a new inseparable symbol (forming a multiple or submultiple of the unit concerned) which can be raised to a positive or negative power and which can be combined with other unit symbols to form compound unit symbols.

Examples: $2.3\ \mathrm{cm}^3 = 2.3\ (\mathrm{cm})^3 = 2.3\ (10^{-2}\ \mathrm{m})^3 = 2.3 \times 10^{-6}\ \mathrm{m}^3$
$1\ \mathrm{cm}^{-1} = 1\ (\mathrm{cm})^{-1} = 1\ (10^{-2}\ \mathrm{m})^{-1} = 10^2\ \mathrm{m}^{-1}$
$5000\ \mu\mathrm{s}^{-1} = 5000\ (\mu\mathrm{s})^{-1} = 5000\ (10^{-6}\ \mathrm{s})^{-1} = 5000 \times 10^6\ \mathrm{s}^{-1} = 5 \times 10^9\ \mathrm{s}^{-1}$
$1\ \mathrm{V/cm} = (1\ \mathrm{V})/(10^{-2}\ \mathrm{m}) = 10^2\ \mathrm{V/m}$

Prefix names are also inseparable from the unit names to which they are attached. Thus, for example, millimeter, micropascal, and meganewton are single words.

6.2.4 Unacceptability of compound prefixes

Compound prefix names or symbols, that is, prefix names or symbols formed by the juxtaposition of two or more prefix names or symbols, are not permitted.

Example: nm (nanometer) *but not*: mμm (millimicrometer)

6.2.5 Use of multiple prefixes

In a derived unit formed by division, the use of a prefix symbol (or a prefix name) in both the numerator *and* the denominator can cause confusion. Thus, for example, 10 kV/mm is acceptable, but 10 MV/m is often considered preferable because it contains only one prefix symbol and it is in the numerator.

In a derived unit formed by multiplication, the use of more than one prefix symbol (or more than one prefix name) can also cause confusion. Thus, for example, 10 MV · ms is acceptable, but 10 kV · s is often considered preferable.

Note: Such considerations usually do not apply if the derived unit involves the kilogram. For example, 0.13 mmol/g is *not* considered preferable to 0.13 mol/kg.

6.2.6 Unacceptability of stand-alone prefixes

Prefix symbols cannot stand alone and thus cannot be attached to the number 1, the symbol for the unit one. In a similar vein, prefix names cannot be attached to the name of the unit one, that is, to the word "one." (See Sec. 7.10 for a discussion of the unit one.)

Example: the number density of Pb atoms is $5 \times 10^6/\mathrm{m}^3$ *but not*: the number density of Pb atoms is $5\ \mathrm{M/m}^3$

6.2.7 Prefixes and the kilogram

For historical reasons, the name "kilogram" for the SI base unit of mass contains the name "kilo," the SI prefix for 10^3. Thus, because compound prefixes are unacceptable (see Sec. 6.2.4), symbols for decimal multiples and submultiples of the unit of mass are formed by attaching SI prefix symbols to g, the

unit symbol for gram, and the names of such multiples and submultiples are formed by attaching SI prefix names to the name "gram."

Example: 10^{-6} kg = 1 mg (1 milligram) *but not*: 10^{-6} kg = 1 μkg (1 microkilogram)

6.2.8 Prefixes with the degree Celsius and units accepted for use with the SI

Prefix symbols may be used with the unit symbol °C and prefix names may be used with the unit name "degree Celsius." For example, 12 m °C (12 millidegrees Celsius) is acceptable. However, to avoid confusion, prefix symbols (and prefix names) are not used with the time-related unit symbols (names) min (minute), h (hour), d (day); nor with the angle-related symbols (names) ° (degree), ' (minute), and " (second) (see Table 6).

Prefix symbols (and prefix names) may be used with the unit symbols (names) L (liter), t (metric ton), eV (electronvolt), u (unified atomic mass unit), Da (dalton) (see Tables 6 and 7). However, although submultiples of the liter such as mL (milliliter) and dL (deciliter) are in common use, multiples of the liter such as kL (kiloliter) and ML (megaliter) are not. Similarly, although multiples of the metric ton such as kt (kilometric ton) are commonly used, submultiples such as mt (millimetric ton), which is equal to the kilogram (kg), are not. Examples of the use of prefix symbols with eV and u are 80 MeV (80 megaelectronvolts) and 15 nu (15 nanounified atomic mass units).

7 Rules and Style Conventions for Expressing Values of Quantities

7.1 Value and numerical value of a quantity

The *value* of a quantity is its magnitude expressed as the product of a number and a unit, and the number multiplying the unit is the *numerical value* of the quantity expressed in that unit.

More formally, the value of quantity A can be written as $A = \{A\}[A]$, where $\{A\}$ is the numerical value of A when the value of A is expressed in the unit $[A]$. The numerical value can therefore be written as $\{A\} = A\,/\,[A]$, which is a convenient form for use in figures and tables. Thus, to eliminate the possibility of misunderstanding, an axis of a graph or the heading of a column of a table can be labeled "t/°C" instead of "t (°C)" or "Temperature (°C)." Similarly, an axis or column heading can be labeled "E/(V/m)" instead of "E (V/m)" or "Electric field strength (V/m)."

Examples:

1. In the SI, the value of the velocity of light in vacuum is c = 299 792 458 m/s exactly. The number 299 792 458 is the numerical value of c when c is expressed in the unit m/s, and equals c/(m/s).

2. The ordinate of a graph is labeled T/(10^3 K), where T is thermodynamic temperature and K is the unit symbol for kelvin, and has scale marks at 0, 1, 2, 3, 4, and 5. If the ordinate value of a point on a curve in the graph is estimated to be 3.2, the corresponding temperature is T / (10^3 K) = 3.2 or T = 3200 K. Notice the lack of ambiguity in this form of labeling compared with "Temperature (10^3 K)."

3. An expression such as ln(p/MPa), where p is the quantity symbol for pressure and MPa is the unit symbol for megapascal, is perfectly acceptable, because p/MPa is the numerical value of p when p is expressed in the unit MPa and is simply a number.

Notes:

1. For the conventions concerning the grouping of digits, see Sec. 10.5.3.

2. An alternative way of writing $c/(\mathrm{m/s})$ is $\{c\}_{\mathrm{m/s}}$, meaning the numerical value of c when c is expressed in the unit m/s.

7.2 Space between numerical value and unit symbol

In the expression for the value of a quantity, the unit symbol is placed after the numerical value and a *space* is left between the numerical value and the unit symbol.

The only exceptions to this rule are for the unit symbols for degree, minute, and second for plane angle: °, ', and ", respectively (see Table 6), in which case no space is left between the numerical value and the unit symbol.

Example: $\alpha = 30°22'8''$

Note: α is a quantity symbol for plane angle.

This rule means that:

(a) The symbol °C for the degree Celsius is preceded by a space when one expresses the values of Celsius temperatures.

Example: $t = 30.2$ °C *but not*: $t = 30.2$°C or $t = 30.2$° C

(b) Even when the value of a quantity is used as an adjective, a space is left between the numerical value and the unit symbol. (This rule recognizes that unit symbols are not like ordinary words or abbreviations but are mathematical entities, and that the value of a quantity should be expressed in a way that is as independent of language as possible—sees Secs. 7.6 and 7.10.3.)

Examples: a 1 m end gauge *but not*: a 1-m end gauge
a 10 kΩ resistor *but not*: a 10-kΩ resistor

However, if there is any ambiguity, the words should be rearranged accordingly. For example, the statement "the samples were placed in 22 mL vials" should be replaced with the statement "the samples were placed in vials of volume 22 mL."

Note: When unit names are spelled out, the normal rules of English apply. Thus, for example, "a roll of 35-millimeter film" is acceptable (see Sec. 7.6, note 3).

7.3 Number of units per value of a quantity

The value of a quantity is expressed using no more than one unit.

Example: $l = 10.234$ m *but not*: $l = 10$ m 23 cm 4 mm

Note: Expressing the values of time intervals and of plane angles are exceptions to this rule. However, it is preferable to divide the degree decimally. Thus one should write 22.20° rather than 22°12', except in fields such as cartography and astronomy.

7.4 Unacceptability of attaching information to units

When one gives the value of a quantity, it is incorrect to attach letters or other symbols to the unit in order to provide information about the quantity or its conditions of measurement. Instead, the letters or other symbols should be attached to the quantity.

Example: $V_{\mathrm{max}} = 1000$ V *but not*: $V = 1000\ \mathrm{V_{max}}$

Note: V is a quantity symbol for potential difference.

7.5 Unacceptability of mixing information with units

When one gives the value of a quantity, any information concerning the quantity or its conditions of measurement must be presented in such a way as not to be associated with the unit. This means that quantities must be defined so that they can be expressed solely in acceptable units (including the unit one — see Sec. 7.10).

Examples:

the Pb content is 5 ng/L	*but not*:	5 ng Pb/L or 5 ng of lead/L
the sensitivity for NO_3 molecules is $5 \times 10^{10}/cm^3$	*but not*:	the sensitivity is 5×10^{10} NO^3 molecules/cm^3
the neutron emission rate is $5 \times 10^{10}/s$	*but not*:	the emission rate is 5×10^{10} n/s
the number density of O_2 atoms is $3 \times 10^{18}/cm^3$	*but not*:	the density is 3×10^{18} O_2 atoms/cm^3
the resistance per square is 100 Ω	*but not*:	the resistance is 100 Ω/square

7.6 Symbols for numbers and units versus spelled-out names of numbers and units

This *Guide* takes the position that the key elements of a scientific or technical paper, particularly the results of measurements and the values of quantities that influence the measurements, should be presented in a way that is as independent of language as possible. This will allow the paper to be understood by as broad an audience as possible, including readers with limited knowledge of English. Thus, to promote the comprehension of quantitative information in general and its broad understandability in particular, values of quantities should be expressed in acceptable units using

— the Arabic symbols for numbers, that is, the Arabic numerals, *not* the spelled-out names of the Arabic numerals; and

— the symbols for the units, *not* the spelled-out names of the units.

Examples:

the length of the laser is 5 m	*but not*:	the length of the laser is five meters
the sample was annealed at a temperature of 955 K for 12 h	*but not*:	the sample was annealed at a temperature of 955 kelvins for 12 hours

Notes:

1. If the intended audience for a publication is unlikely to be familiar with a particular unit symbol, it should be defined when first used.

2. Because the use of the spelled-out name of an Arabic numeral with a unit symbol can cause confusion, such combinations must strictly be avoided. For example, one should never write "the length of the laser is five m."

3. Occasionally, a value is used in a descriptive or literary manner and it is fitting to use the spelled-out name of the unit rather than its symbol. Thus, this Guide considers acceptable statements such

as "the reading lamp was designed to take two 60-watt light bulbs," or "the rocket journeyed uneventfully across 380 000 kilometers of space," or "they bought a roll of 35-millimeter film for their camera."

4. The United States Government Printing Office Style Manual (Ref. [3], pp. 181-189) gives the rule that symbols for numbers are always to be used when one expresses (a) the value of a quantity in terms of a unit of measurement, (b) time (including dates), and (c) an amount of money. This publication should be consulted for the rules governing the choice between the use of symbols for numbers and the spelled-out names of numbers when numbers are dealt with in general.

7.7 Clarity in writing values of quantities

The value of a quantity is expressed as the product of a number and a unit (see Sec. 7.1). Thus, to avoid possible confusion, this *Guide* takes the position that values of quantities must be written so that it is completely clear to which unit symbols the numerical values of the quantities belong. Also to avoid possible confusion, this *Guide* strongly recommends that the word "to" be used to indicate a range of values for a quantity instead of a range dash (that is, a long hyphen) because the dash could be misinterpreted as a minus sign. (The first of these recommendations once again recognizes that unit symbols are not like ordinary words or abbreviations but are mathematical entities—see Sec. 7.2.)

Examples:

51 mm × 51 mm × 25 mm	*but not*:	51 × 51 × 25 mm
225 nm to 2400 nm or (225 to 2400) nm	*but not*:	225 to 2400 nm
0 °C to 100 °C or (0 to 100) °C	*but not*:	0 °C − 100 °C
0 V to 5 V or (0 to 5) V	*but not*:	0 − 5 V
(8.2, 9.0, 9.5, 9.8, 10.0) GHz	*but not*:	8.2, 9.0, 9.5, 9.8, 10.0 GHz
63.2 m ± 0.1 m or (63.2 ± 0.1) m	*but not*:	63.2 ± 0.1 m or 63.2 m ± 0.1
129 s − 3 s = 126 s or (129 − 3) s = 126 s	*but not*:	129 − 3 s = 126 s

Note: For the conventions concerning the use of the multiplication sign, see Sec. 10.5.4.

7.8 Unacceptability of stand-alone unit symbols

Symbols for units are never used without numerical values or quantity symbols (they are not abbreviations).

Examples: there are 10^6 mm in 1 km *but not*: there are many mm in a km
it is sold by the cubic meter *but not*: it is sold by the m^3
t/°C, E/(V/m), p/MPa, and the like are perfectly acceptable (see Sec. 7.1).

7.9 Choosing SI prefixes

The selection of the appropriate decimal multiple or submultiple of a unit for expressing the value of a quantity, and thus the choice of SI prefix, is governed by several factors.

These include:
— the need to indicate which digits of a numerical value are significant,
— the need to have numerical values that are easily understood, and

— the practice in a particular field of science or technology.

A digit is significant if it is required to express the numerical value of a quantity. In the expression $l = 1200$ m, it is not possible to tell whether the last two zeroes are significant or only indicate the magnitude of the numerical value of l. However, in the expression $l = 1.200$ km, which uses the SI prefix symbol for 10^3 (kilo, symbol k), the two zeroes are assumed to be significant because if they were not, the value of l would have been written $l = 1.2$ km.

It is often recommended that, for ease of understanding, prefix symbols should be chosen in such a way that numerical values are between 0.1 and 1000, and that only prefix symbols that represent the number 10 raised to a power that is a multiple of 3 should be used.

Examples: 3.3×10^7 Hz may be written as 33×10^6 Hz = 33 MHz
0.009 52 g may be written as 9.52×10^{-3} g = 9.52 mg
2703 W may be written as 2.703×10^3 W = 2.703 kW
5.8×10^{-8} m may be written as 58×10^{-9} m = 58 nm

However, the values of quantities do not always allow this recommendation to be followed, nor is it mandatory to try to do so.

In a table of values of the same kind of quantities or in a discussion of such values, it is usually recommended that only one prefix symbol should be used even if some of the numerical values are not between 0.1 and 1000. For example, it is often considered preferable to write "the size of the sample is 10 mm × 3 mm × 0.02 mm" rather than "the size of the sample is 1 cm × 3 mm × 20 µm."

In certain kinds of engineering drawings it is customary to express all dimensions in millimeters. This is an example of selecting a prefix based on the practice in a particular field of science or technology.

7.10 Values of quantities expressed simply as numbers: the unit one, symbol 1

Certain quantities, such as refractive index, relative permeability, and mass fraction, are defined as the ratio of two mutually comparable quantities and thus are of dimension one (see Sec. 7.14). The coherent SI unit for such a quantity is the ratio of two identical SI units and may be expressed by the number 1. However, the number 1 generally does not appear in the expression for the value of a quantity of dimension one. For example, the value of the refractive index of a given medium is expressed as $n = 1.51 \times 1 = 1.51$.

On the other hand, certain quantities of dimension one have units with special names and symbols which can be used or not depending on the circumstances. Plane angle and solid angle, for which the SI units are the radian (rad) and steradian (sr), respectively, are examples of such quantities (see Sec. 4.2.1).

7.10.1 Decimal multiples and submultiples of the unit one

Because SI prefix symbols cannot be attached to the unit one (see Sec. 6.2.6), powers of 10 are used to express decimal multiples and submultiples of the unit one.

Example: $\mu_r = 1.2 \times 10^{-6}$ *but not*: $\mu_r = 1.2$ µ

Note: μ_r is the quantity symbol for relative permeability.

7.10.2 %, percentage by, fraction

In keeping with Ref. [4: ISO 31-0], this *Guide* takes the position that it is acceptable to use the internationally recognized symbol % (percent) for the number 0.01 with the SI and thus to express the values of quantities of dimension one (see Sec. 7.14) with its aid. When it is used, a space is left between

the symbol % and the number by which it is multiplied [4: ISO 31-0]. Further, in keeping with Sec. 7.6, the symbol % should be used, not the name "percent."

Example: $x_B = 0.0025 = 0.25\ \%$ *but not*: $x_B = 0.0025 = 0.25\%$ or $x_B = 0.25$ percent

Note: x_B is the quantity symbol for amount-of-substance fraction of B (see Sec. 8.6.2).

Because the symbol % represents simply a number, it is not meaningful to attach information to it (see Sec. 7.4). One must therefore avoid using phrases such as "percentage by weight," "percentage by mass," "percentage by volume," or "percentage by amount of substance." Similarly, one must avoid writing, for example, "% (*m*/*m*)," "% (by weight)," "% (*V*/*V*)," "% (by volume)," or "% (mol/mol)." The preferred forms are "the mass fraction is 0.10," or "the mass fraction is 10 %," or "$w_B = 0.10$," or "$w_B = 10\ \%$" (w_B is the quantity symbol for mass fraction of B—see Sec. 8.6.10); "the volume fraction is 0.35," or "the volume fraction is 35 %," or "$\varphi_B = 0.35$," or "$\varphi_B = 35\ \%$" (φ_B is the quantity symbol for volume fraction of B—see Sec. 8.6.6); and "the amount-of-substance fraction is 0.15," or "the amount-of-substance fraction is 15 %," or "$x_B = 0.15$," or "$x_B = 15\ \%$." Mass fraction, volume fraction, and amount-of-substance fraction of B may also be expressed as in the following examples: $w_B = 3$ g/kg; $\varphi_B = 6.7$ mL/L; $x_B = 185$ mmol/mol. Such forms are highly recommended (see also Sec. 7.10.3).

In the same vein, because the symbol % represents simply the number 0.01, it is incorrect to write, for example, "where the resistances R_1 and R_2 differ by 0.05 %," or "where the resistance R_1 exceeds the resistance R_2 by 0.05 %." Instead, one should write, for example, "where $R_1 = R_2\ (1 + 0.05\ \%)$," or define a quantity Δ via the relation $\Delta = (R_1 - R_2) / R_2$ and write "where $\Delta = 0.05\ \%$." Alternatively, in certain cases, the word "fractional" or "relative" can be used. For example, it would be acceptable to write "the fractional increase in the resistance of the 10 kΩ reference standard in 2006 was 0.002 %."

7.10.3 ppm, ppb, and ppt

In keeping with Ref. [4: ISO 31-0], this *Guide* takes the position that the language-dependent terms part per million, part per billion, and part per trillion, and their respective abbreviations "ppm," "ppb," and "ppt" (and similar terms and abbreviations), are not acceptable for use with the SI to express the values of quantities. Forms such as those given in the following examples should be used instead.

Examples:

a stability of 0.5 (μA/A)/min *but not*: a stability of 0.5 ppm/min

a shift of 1.1 nm/m *but not*: a shift of 1.1 ppb

a frequency change of $0.35 \times 10^{-9} f$ *but not*: a frequency change of 0.35 ppb

a sensitivity of 2 ng/kg *but not*: a sensitivity of 2 ppt

the relative expanded uncertainty of the resistance R is $U_r = 3\ \mu\Omega/\Omega$

or

the expanded uncertainty of the resistance R is $U = 3 \times 10^{-6} R$

or

the relative expanded uncertainty of the resistance R is $U_r = 3 \times 10^{-6}$

but not:

the relative expanded uncertainty of the resistance R is $U_r = 3$ ppm

Because the names of numbers 10^9 and larger are not uniform worldwide, it is best that they be avoided entirely (in many countries, 1 billion = 1×10^{12}, not 1×10^9 as in the United States); the preferred way of expressing large numbers is to use powers of 10. This ambiguity in the names of numbers is one of the reasons why the use of ppm, ppb, ppt, and the like is deprecated. Another, and a more important one, is that it is inappropriate to use abbreviations that are language dependent together with internationally recognized signs and symbols, such as MPa, ln, 10^{13}, and %, to express the values of quantities and in equations or other mathematical expressions (see also Sec. 7.6).

Note: This *Guide* recognizes that in certain cases the use of ppm, ppb, and the like may be required by a law or a regulation. Under these circumstances, Secs. 2.1 and 2.1.1 apply.

7.10.4 Roman numerals

It is unacceptable to use Roman numerals to express the values of quantities. In particular, one should not use C, M, and MM as substitutes for 10^2, 10^3, and 10^6, respectively.

7.11 Quantity equations and numerical-value equations

A quantity equation expresses a relation among quantities. An example is $l = vt$, where l is the distance a particle in uniform motion with velocity v travels in the time t.

Because a quantity equation such as $l = vt$ is independent of the units used to express the values of the quantities that compose the equation, and because l, v, and t represent quantities and not numerical values of quantities, it is incorrect to associate the equation with a statement such as "where l is in meters, v is in meters per second, and t is in seconds."

On the other hand, a numerical value equation expresses a relation among numerical values of quantities and therefore does depend on the units used to express the values of the quantities. For example, $\{l\}_{\mathrm{m}} = 3.6^{-1}\ \{v\}_{\mathrm{km/h}}\ \{t\}_{\mathrm{s}}$ expresses the relation among the numerical values of l, v, and t only when the values of l, v, and t are expressed in the units meter, kilometer per hour, and second, respectively. (Here $\{A\}_{\mathrm{X}}$ is the numerical value of quantity A when its value is expressed in the unit X—see Sec. 7.1, note 2.)

An alternative way of writing the above numerical value equation, and one that is preferred because of its simplicity and generality, is $l/\mathrm{m} = 3.6^{-1}\ [v/(\mathrm{km/h})](t\ /\ \mathrm{s})$. NIST authors should consider using this preferred form instead of the more traditional form "$l = 3.6^{-1}\ vt$, where l is in meters, v is in kilometers per hour, and t is in seconds." In fact, this form is still ambiguous because no clear distinction is made between a quantity and its numerical value. The correct statement is, for example, "$l^* = 3.6^{-1}\ v^*\ t^*$, where l^* is the numerical value of the distance l traveled by a particle in uniform motion when l is expressed in meters, v^* is the numerical value of the velocity v of the particle when v is expressed in kilometers per hour, and t^* is the numerical value of the time of travel t of the particle when t is expressed in seconds." Clearly, as is done here, it is important to use different symbols for quantities and their numerical values to avoid confusion.

It is the strong recommendation of this *Guide* that because of their universality, quantity equations should be used in preference to numerical-value equations. Further, if a numerical-value equation is used, it should be written in the preferred form given in the above paragraph, and if at all feasible the quantity equation from which it was obtained should be given.

Notes:

1. Two other examples of numerical-value equations written in the preferred form are as follows, where E_g is the gap energy of a compound semiconductor and k is the conductivity of an electrolytic solution:

$$E_g/\text{eV} = 1.425 - 1.337x + 0.270x^2,\ 0 \le x \le 0.15,$$

where x is an appropriately defined amount-of-substance fraction (see Sec. 8.6.2).

$k/(\text{S}/\text{cm}) = 0.065\ 135 + 1.7140 \times 10^{-3}(t/°\text{C}) + 6.4141 \times 10^{-6}(t/°\text{C})^2 - 4.5028 \times 10^{-8}(t/°\text{C})^3$, $0\ °\text{C} \le t \le 50\ °\text{C}$, where t is Celsius temperature.

2. Writing numerical-value equations for quantities expressed in inch-pound units in the preferred form will simplify their conversion to numerical-value equations for the quantities expressed in SI units.

7.12 Proper names of quotient quantities

Derived quantities formed from other quantities by division are written using the words "divided by" or per rather than the words "per unit" in order to avoid the appearance of associating a particular unit with the derived quantity.

Example: pressure is force divided by area or pressure is force per area *but not*: pressure is force per unit area

7.13 Distinction between an object and its attribute

To avoid confusion, when discussing quantities or reporting their values, one should distinguish between a phenomenon, body, or substance, and an attribute ascribed to it. For example, one should recognize the difference between a body and its mass, a surface and its area, a capacitor and its capacitance, and a coil and its inductance. This means that although it is acceptable to say "an object of mass 1 kg was attached to a string to form a pendulum," it is not acceptable to say "a mass of 1 kg was attached to a string to form a pendulum."

7.14 Dimension of a quantity

Any SI derived quantity Q can be expressed in terms of the SI base quantities length (l), mass (m), time (t), electric current (I), thermodynamic temperature (T), amount of substance (n), and luminous intensity (I_v) by an equation of the form

$$Q = l^{\alpha} m^{\beta} t^{\gamma} I^{\delta} T^{\varepsilon} n^{\zeta} I_v^{\eta} \sum_{k=1}^{K} a_k ,$$

where the exponents α, β, γ, . . . are numbers and the factors a_k are also numbers. The dimension of Q is defined to be

$$\dim Q = \mathsf{L}^{\alpha}\mathsf{M}^{\beta}\mathsf{T}^{\gamma}\mathsf{I}^{\delta}\Theta^{\varepsilon}\mathsf{N}^{\zeta}\mathsf{J}^{\eta} .$$

where L, M, T, I, Θ, N, and J are the *dimensions* of the SI base quantities length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity, respectively. The exponents α, β, γ, . . . are called "dimensional exponents." The SI derived unit of Q is $\text{m}^{\alpha}\cdot\text{kg}^{\beta}\cdot\text{s}^{\gamma}\cdot\text{A}^{\delta}\cdot\text{K}^{\varepsilon}\cdot\text{mol}^{\zeta}\cdot\text{cd}^{\eta}$, which is obtained by replacing the dimensions of the SI base quantities in the dimension of Q with the symbols for the corresponding base units.

Example: Consider a nonrelativistic particle of mass m in uniform motion which travels a distance l in a time t. Its velocity is $\upsilon = l/t$ and its kinetic energy is $E_k = m\upsilon^2/2 = l^2 mt^{-2}/2$. The dimension of E_k is $\dim E_k = \mathsf{L}^2\mathsf{M}\mathsf{T}^{-2}$ and the dimensional exponents are 2, 1, and −2. The SI derived unit of E_k is then $\text{m}^2\cdot\text{kg}\cdot\text{s}^{-2}$, which is given the special name "joule" and special symbol J.

A derived quantity of dimension one, which is sometimes called a "dimensionless quantity," is one for which all of the dimensional exponents are zero: dim $Q = 1$. It therefore follows that the derived unit for such a quantity is also the number one, symbol 1, which is sometimes called a "dimensionless derived unit."

Example: The mass fraction w_B of a substance B in a mixture is given by $w_B = m_B / m$, where m_B is the mass of B and m is the mass of the mixture (see Sec. 8.6.10). The dimension of w_B is dim $w_B = \mathsf{M}^1\mathsf{M}^{-1} = 1$; all of the dimensional exponents of w_B are zero, and its derived unit is $\mathrm{kg}^1 \cdot \mathrm{kg}^{-1} = 1$ also.

8 Comments on Some Quantities and Their Units

8.1 Time and rotational frequency

The SI unit of time (actually time interval) is the second (s) and should be used in all technical calculations. When time relates to calendar cycles, the minute (min), hour (h), and day (d) might be necessary. For example, the kilometer per hour (km/h) is the usual unit for expressing vehicular speeds. Although there is no universally accepted symbol for the year, Ref. [4: ISO 80000-3] suggests the symbol a.

The rotational frequency n of a rotating body is defined to be the number of revolutions it makes in a time interval divided by that time interval [4: ISO 80000-3]. The SI unit of this quantity is thus the reciprocal second (s^{-1}). However, as pointed out in Ref. [4: ISO 80000-3], the designations "revolutions per second" (r/s) and "revolutions per minute" (r/min) are widely used as units for rotational frequency in specifications on rotating machinery.

8.2 Volume

The SI unit of volume is the cubic meter (m^3) and may be used to express the volume of any substance, whether solid, liquid, or gas. The liter (L) is a special name for the cubic decimeter (dm^3), but the CGPM recommends that the liter not be used to give the results of high accuracy measurements of volumes [1, 2]. Also, it is not common practice to use the liter to express the volumes of solids nor to use multiples of the liter such as the kiloliter (kL) [see Sec. 6.2.8, and also Table 6, footnote (*b*)].

8.3 Weight

In science and technology, the weight of a body in a particular reference frame is defined as the force that gives the body an acceleration equal to the local acceleration of free fall in that reference frame [4: ISO 80000-4]. Thus the SI unit of the quantity weight defined in this way is the newton (N). When the reference frame is a celestial object, Earth for example, the weight of a body is commonly called the local force of gravity on the body.

Example: The local force of gravity on a copper sphere of mass 10 kg located on the surface of the Earth, which is its weight at that location, is approximately 98 N.

Note: The local force of gravity on a body, that is, its weight, consists of the resultant of all the gravitational forces acting on the body and the local centrifugal force due to the rotation of the celestial object. The effect of atmospheric buoyancy is usually excluded, and thus the weight of a body is generally the local force of gravity on the body in vacuum.

In commercial and everyday use, and especially in common parlance, weight is usually used as a synonym for mass. Thus the SI unit of the quantity weight used in this sense is the kilogram (kg) and the verb "to weigh" means "to determine the mass of" or "to have a mass of."

Examples: the child's weight is 23 kg the briefcase weighs 6 kg Net wt. 227 g

Inasmuch as NIST is a scientific and technical organization, the word "weight" used in the everyday sense (that is, to mean mass) should appear only occasionally in NIST publications; the word "mass" should be used instead. In any case, in order to avoid confusion, whenever the word "weight" is used, it should be made clear which meaning is intended.

8.4 Relative atomic mass and relative molecular mass

The terms atomic weight and molecular weight are obsolete and thus should be avoided. They have been replaced by the equivalent but preferred terms relative atomic mass, symbol A_r, and relative molecular mass, symbol M_r, respectively [4: ISO 31-8], which better reflect their definitions. Similar to atomic weight and molecular weight, relative atomic mass and relative molecular mass are quantities of dimension one and are expressed simply as numbers. The definitions of these quantities are as follows [4: ISO 31-8]:

Relative atomic mass (formerly atomic weight): ratio of the average mass per atom of an element to 1/12 of the mass of the atom of the nuclide ^{12}C.

Relative molecular mass (formerly molecular weight): ratio of the average mass per molecule or specified entity of a substance to 1/12 of the mass of an atom of the nuclide ^{12}C.

Examples: $A_r(Si) = 28.0855$ $M_r(H_2) = 2.0159$ $A_r(^{12}C) = 12$ exactly

Notes:

1. It follows from these definitions that if X denotes a specified atom or nuclide and B a specified molecule or entity (or more generally, a specified substance), then Ar(X) = m(X) / [m(12C) / 12] and Mr(B) = m(B) / [m(12C) / 12], where m(X) is the mass of X, m(B) is the mass of B, and m(12C) is the mass of an atom of the nuclide 12C. It should also be recognized that m(12C) / 12 = u, the unified atomic mass unit, which is approximately equal to $1.66\ 3\ 10^{-27}$ kg [see Table 7, footnote (*d*)].

2. It follows from the examples and note 1 that the respective average masses of Si, H_2, and ^{12}C are $m(Si) = A_r(Si)$ u, $m(H_2) = M_r(H_2)$ u, and $m(^{12}C) = A_r(^{12}C)$ u.

3. In publications dealing with mass spectrometry, one often encounters statements such as "the mass-to-charge ratio is 15." What is usually meant in this case is that the ratio of the nucleon number (that is, mass number—see Sec. 10.4.2) of the ion to its number of charges is 15. Thus mass-to-charge ratio is a quantity of dimension one, even though it is commonly denoted by the symbol m / z. For example, the mass-to-charge ratio of the ion $^{12}C_7{}^1H_7{}^{++}$ is 91/2 = 45.5.

8.5 Temperature interval and temperature difference

As discussed in Sec. 4.2.1.1, Celsius temperature (t) is defined in terms of thermodynamic temperature (T) by the equation $t = T - T_0$, where $T_0 = 273.15$ K by definition. This implies that the numerical value of a given temperature interval or temperature difference whose value is expressed in the unit degree Celsius (°C) is equal to the numerical value of the same interval or difference when its value is expressed in the unit kelvin (K); or in the notation of Sec. 7.1, note 2, $\{\Delta t\}_{°C} = \{\Delta T\}_K$. Thus temperature intervals or temperature differences may be expressed in either the degree Celsius or the kelvin using the same numerical value.

Example: The difference in temperature between the freezing point of gallium and the triple point of water is $\Delta t = 29.7546$ °C $= \Delta T = 29.7546$ K.

8.6 Amount of substance, concentration, molality, and the like

The following section discusses amount of substance, and the subsequent nine sections, which are based on Ref. [6: ISO 31-8] and which are succinctly summarized in Table 12, discuss quantities that are quotients involving amount of substance, volume, or mass. In the table and its associated sections, symbols for substances are shown as subscripts, for example, x_B, n_B, b_B. However, it is generally preferable to place symbols for substances and their states in parentheses immediately after the quantity symbol, for example $n(H_2SO_4)$. (For a detailed discussion of the use of the SI in physical chemistry, see the book cited in Ref. [6], note 3.)

8.6.1 Amount of substance

Quantity symbol: n (also ν). SI unit: mole (mol).

Definition: See Sec. A.7.

Notes:

1. Amount of substance is one of the seven base quantities upon which the SI is founded (see Sec. 4.1 and Table 1).

2. In general, $n(x\mathrm{B}) = n(\mathrm{B}) / x$, where x is a number. Thus, for example, if the amount of substance of H_2SO_4 is 5 mol, the amount of substance of $(1/3)H_2SO_4$ is 15 mol: $n[(1/3)H_2SO_4] = 3n(H_2SO_4)$.

Example: The relative atomic mass of a fluorine atom is $A_r(\mathrm{F}) = 18.9984$. The relative molecular mass of a fluorine molecule may therefore be taken as $M_r(\mathrm{F}_2) = 2A_r(\mathrm{F}) = 37.9968$. The molar mass of F_2 is then $M(\mathrm{F}_2) = 37.9968 \times 10^{-3}$ kg/mol = 37.9968 g/mol (see Sec. 8.6.4). The amount of substance of, for example, 100 g of F_2 is then $n(\mathrm{F}_2) = 100$ g / (37.9968 g/mol) = 2.63 mol.

8.6.2 Mole fraction of B; amount-of-substance fraction of B

Quantity symbol: x_B (also y_B). SI unit: one (1) (amount-of-substance fraction is a quantity of dimension one).

Definition: ratio of the amount of substance of B to the amount of substance of the mixture: $x_B = n_B/n$.

Table 12. Summary description of nine quantities that are quotients involving amount of substance, volume, or mass[(a)]

Quantity in denominator	Quantity in numerator: Amount of Substance **Symbol:** n **SI unit:** mol	Quantity in numerator: Volume **Symbol:** V **SI unit:** m^3	Quantity in numerator: Mass **Symbol:** m **SI unit:** kg
Amount of Substance **Symbol:** n **SI unit:** mol	amount-of-substance fraction $x_B = \frac{n_B}{n}$ ***SI unit:*** mol/mol = 1	molar volume $V_m = \frac{V}{n}$ ***SI unit:*** m^3/mol	molar mass $M = \frac{m}{n}$ ***SI unit:*** kg/mol
Volume **Symbol:** V **SI unit:** m^3	amount-of-substance concentration $c_B = \frac{n_B}{V}$ ***SI unit:*** mol/mol^3	volume fraction $\varphi_B = \frac{x_B V^*_{m,B}}{\sum x_A V^*_{m,A}}$ ***SI unit:*** $m^3/m^3 = 1$	mass density $\rho = \frac{m}{V}$ ***SI unit:*** kg/m^3
Mass **Symbol:** m **SI unit:** kg	molality $b_B = \frac{n_B}{m_A}$ ***SI unit:*** mol/kg	specific volume $\upsilon = \frac{V}{m}$ ***SI unit:*** m^3/kg	mass fraction $w_B = \frac{m_B}{m}$ ***SI unit:*** kg/kg = 1

[(a)] Adapted from *Canadian Metric Practice Guide* (see Ref. [6], note 2; the book cited in Ref. [6], note 3, may also be consulted).

Notes:

1. This quantity is commonly called "mole fraction of B" but this *Guide* prefers the name "amount-of-substance fraction of B," because it does not contain the name of the unit mole (compare kilogram fraction to mass fraction).

2. For a mixture composed of substances A, B, C, . . . , $n_A + n_B + n_C + ... \equiv \sum_A n_A$

3. A related quantity is *amount-of-substance ratio of B* (commonly called "mole ratio of solute B"), symbol r_B. It is the ratio of the amount of substance of B to the amount of substance of the solvent substance: $r_B = n_B/n_S$. For a single solute C in a solvent substance (a one-solute solution), $r_C = x_C/(1 - x_C)$. This follows from the relations $n = n_C + n_S$, $x_C = n_C / n$, and $r_C = n_C / n_S$, where the solvent substance S can itself be a mixture.

8.6.3 Molar volume

Quantity symbol: V_m. SI unit: cubic meter per mole (m^3/mol).

Definition: volume of a substance divided by its amount of substance: $V_m = V/n$.

Notes:

1. The word "molar" means "divided by amount of substance."

2. For a mixture, this term is often called "mean molar volume."

3. The amagat should not be used to express molar volumes or reciprocal molar volumes. (One amagat is the molar volume V_m of a real gas at p = 101 325 Pa and T = 273.15 K and is approximately equal to 22.4 × 10^{-3} m^3/mol. The name "amagat" is also given to $1/V_m$ of a real gas at p = 101 325 Pa and T = 273.15 K and in this case is approximately equal to 44.6 mol/m^3.)

8.6.4 Molar mass

Quantity symbol: M. SI unit: kilogram per mole (kg/mol).

Definition: mass of a substance divided by its amount of substance: $M = m/n$.

Notes:

1. For a mixture, this term is often called "mean molar mass."

2. The molar mass of a substance B of definite chemical composition is given by $M(\mathrm{B})$ = $M_r(\mathrm{B}) \times 10^{-3}$ kg/mol = $M_r(\mathrm{B})$ kg/kmol = M_r g/mol, where $M_r(\mathrm{B})$ is the relative molecular mass of B (see Sec. 8.4). The molar mass of an atom or nuclide X is $M(X)$ = $A_r(X) \times 10^{-3}$ kg/mol = $A_r(X)$ kg/kmol = $A_r(X)$ g/mol, where $A_r(X)$ is the relative atomic mass of X (see Sec. 8.4).

8.6.5 Concentration of B; amount-of-substance concentration of B

Quantity symbol: c_B. SI unit: mole per cubic meter (mol/m^3).

Definition: amount of substance of B divided by the volume of the mixture: $c_B = n_B/V$.

Notes:

1. This *Guide* prefers the name "amount-of-substance concentration of B" for this quantity because it is unambiguous. However, in practice, it is often shortened to amount concentration of B, or even simply to concentration of B. Unfortunately, this last form can cause confusion because there are several different "concentrations," for example, mass concentration of B, $\rho_B = m_B/V$; and molecular concentration of B, $C_B = N_B/V$, where N_B is the number of molecules of B.

2. The term normality and the symbol N should no longer be used because they are obsolete. One should avoid writing, for example, "a 0.5 N solution of H_2SO_4" and write instead "a solution having an amount-of-substance concentration of c [(1/2)H_2SO_4]) = 0.5 mol/dm^3" (or 0.5 kmol/m^3 or 0.5 mol/L since 1 mol/dm^3 = 1 kmol/m^3 = 1 mol/L).

3. The term molarity and the symbol M should no longer be used because they, too, are obsolete. One should use instead amount-of-substance concentration of B and such units as mol/dm^3, kmol/m^3, or mol/L. (A solution of, for example, 0.1 mol/dm^3 was often called a 0.1 molar solution, denoted 0.1 M solution. The molarity of the solution was said to be 0.1 M.)

8.6.6 Volume fraction of B

Quantity symbol: φ_B. SI unit: one (1) (volume fraction is a quantity of dimension one).

Definition: for a mixture of substances A, B, C, . . . ,

$$\varphi_{\mathrm{B}} = \frac{x_{\mathrm{B}} V^{*}_{\mathrm{m,B}}}{\sum x_{\mathrm{A}} V^{*}_{\mathrm{m,A}}}$$

where x_{A}, x_{B}, x_{C}, . . . are the amount-of-substance fractions of A, B, C, . . ., $V^{*}_{\mathrm{m,A}}$, $V^{*}_{\mathrm{m,B}}$, $V^{*}_{\mathrm{m,C}}$, . . . are the molar volumes of the pure substances A, B, C, . . . at the same temperature and pressure, and where the summation is over all the substances A, B, C, . . . so that $\sum x_{\mathrm{A}} = 1$.

8.6.7 Mass density; density

Quantity symbol: ρ. SI unit: kilogram per cubic meter ($\mathrm{kg/m^3}$).

Definition: mass of a substance divided by its volume: $\rho = m / V$.

Notes:

1. This *Guide* prefers the name "mass density" for this quantity because there are several different "densities," for example, number density of particles, $n = N / V$; and charge density, $\rho = Q / V$.

2. Mass density is the reciprocal of specific volume (see Sec. 8.6.9): $\rho = 1 / v$.

8.6.8 Molality of solute B

Quantity symbol: b_{B} (also m_{B}). SI unit: mole per kilogram (mol/kg).

Definition: amount of substance of solute B in a solution divided by the mass of the solvent: $b_{\mathrm{B}} = n_{\mathrm{B}} / m_{\mathrm{A}}$.

Note: The term molal and the symbol m should no longer be used because they are obsolete. One should use instead the term molality of solute B and the unit mol/kg or an appropriate decimal multiple or submultiple of this unit. (A solution having, for example, a molality of 1 mol/kg was often called a 1 molal solution, written 1 m solution.)

8.6.9 Specific volume

Quantity symbol: v. SI unit: cubic meter per kilogram ($\mathrm{m^3/kg}$).

Definition: volume of a substance divided by its mass: $v = V / m$.

Note: Specific volume is the reciprocal of mass density (see Sec. 8.6.7): $v = 1 / \rho$.

8.6.10 Mass fraction of B

Quantity symbol: w_{B}. SI unit: one (1) (mass fraction is a quantity of dimension one).

Definition: mass of substance B divided by the mass of the mixture: $w_{\mathrm{B}} = m_{\mathrm{B}} / m$.

8.7 Logarithmic quantities and units: level, neper, bel

This section briefly introduces logarithmic quantities and units. It is based on Ref. [5: IEC 60027-3], which should be consulted for further details. Two of the most common logarithmic quantities are level-of-a-field-quantity, symbol L_F, and level-of-a-power-quantity, symbol L_P; and two of the most common logarithmic units are the units in which the values of these quantities are expressed: the neper, symbol Np, or the bel, symbol B, and decimal multiples and submultiples of the neper and bel formed by attaching SI

prefixes to them, such as the millineper, symbol mNp (1 mNp = 0.001 Np), and the decibel, symbol dB (1 dB = 0.1 B).

Level-of-a-field-quantity is defined by the relation $L_F = \ln(F/F_0)$, where F/F_0 is the ratio of two amplitudes of the same kind, F_0 being a reference amplitude. Level-of-a-power-quantity is defined by the relation $L_P = (1/2)\ln(P/P_0)$, where P/P_0 is the ratio of two powers, P_0 being a reference power. (Note that if $P/P_0 = (F/F_0)^2$, then $L_P = L_F$.) Similar names, symbols, and definitions apply to levels based on other quantities which are linear or quadratic functions of the amplitudes, respectively. In practice, the name of the field quantity forms the name of L_F and the symbol F is replaced by the symbol of the field quantity. For example, if the field quantity in question is electric field strength, symbol E, the name of the quantity is "level-of-electric-field-strength" and it is defined by the relation $L_E = \ln(E/E_0)$.

The difference between two levels-of-a-field-quantity (called "field-level difference") having the same reference amplitude F_0 is $\Delta L_F = L_{F_1} - L_{F_2} = \ln(F_1/F_0) - \ln(F_2/F_0) = \ln(F_1/F_2)$, and is independent of F_0. This is also the case for the difference between two levels-of-a-power-quantity (called "power-level difference") having the same reference power P_0: $\Delta L_P = L_{P_1} - L_{P_2} = \ln(P_1/P_0) - \ln(P_2/P_0) = \ln(P_1/P_2)$.

It is clear from their definitions that both L_F and L_P are quantities of dimension one and thus have as their units the unit one, symbol 1. However, in this case, which recalls the case of plane angle and the radian (and solid angle and the steradian), it is convenient to give the unit one the special name "neper" or "bel" and to define these so-called dimensionless units as follows:

One neper (1 Np) is the level-of-a-field-quantity when $F/F_0 = \mathrm{e}$, that is, when $\ln(F/F_0) = 1$. Equivalently, 1 Np is the level-of-a-power-quantity when $P/P_0 = e^2$, that is, when $(1/2)\ln(P/P_0) = 1$. These definitions imply that the *numerical value* of L_F when L_F is expressed in the unit neper is $\{L_F\}_{\mathrm{Np}} = \ln(F/F_0)$, and that the *numerical value* of L_P when L_P is expressed in the unit neper is $\{L_P\}_{\mathrm{Np}} = (1/2)\ln(P/P_0)$; that is

$$L_F = \ln(F/F_0)\ \mathrm{Np}$$

$$L_P = (1/2)\ln(P/P_0)\ \mathrm{Np}.$$

One bel (1 B) is the level-of-a-field-quantity when $F/F_0 = \sqrt{10}$, that is, when $2\lg(F/F_0) = 1$ (note that $\lg x = \log_{10} x$ – see Sec. 10.1.2). Equivalently, 1 B is the level- of-a-power-quantity when $P/P_0 = 10$, that is, when $\lg(P/P_0) = 1$. These definitions imply that the *numerical value* of L_F when L_F is expressed in the unit bel is $\{L_F\}_{\mathrm{B}} = 2\lg(F/F_0)$ and that the *numerical value* of L_P when L_P is expressed in the unit bel is $\{L_P\}_{\mathrm{B}} = \lg(P/P_0)$; that is

$$L_F = 2\lg(F/F_0)\ \mathrm{B} = 20\lg(F/F_0)\ \mathrm{dB}$$

$$L_P = \lg(P/P_0)\ \mathrm{B} = 10\lg(P/P_0)\ \mathrm{dB}.$$

Since the value of L_F (or L_P) is independent of the unit used to express that value, one may equate L_F in the above expressions to obtain $\ln(F/F_0)\ \mathrm{Np} = 2\lg(F/F_0)\ \mathrm{B}$, which implies

$$1\ \mathrm{B} = \frac{\ln 10}{2}\ \mathrm{Np\ exactly}$$

$$\approx 1.151\,293\ \mathrm{Np}$$

$$1\ \mathrm{dB} \approx 0.115\,129\,3\ \mathrm{Np}.$$

When reporting values of L_F and L_P, one must always give the reference level. According to Ref. [5: IEC 60027-3], this may be done in one of two ways: L_x (re x_{ref}) or $L_{x\ x_{\mathrm{ref}}}$ where x is the quantity symbol for

the quantity whose level is being reported, for example, electric field strength E or sound pressure p, and x_{ref} is the value of the reference quantity, for example, 1 μV/m for E_0, and 20 μPa for p_0. Thus

$$L_E \text{ (re 1 μV/m)} = -0.58 \text{ Np} \qquad \text{or} \qquad L_{E/(1\ \mu\text{V/m})} = -0.58 \text{ Np}$$

means that the level of a certain electric field strength is 0.58 Np *below* the reference electric field strength $E_0 = 1$ μV/m. Similarly

$$L_p \text{ (re 20 μPa)} = 25 \text{ dB} \qquad \text{or} \qquad L_{p/(20\ \mu\text{Pa})} = 25 \text{ dB}$$

means that the level of a certain sound pressure is 25 dB *above* the reference pressure $p_0 = 20$ μPa.

Notes:

1. When such data are presented in a table or in a figure, the following condensed notation may be used instead: − 0.58 Np (1 μV/m); 25 dB (20 μPa).

2. When the same reference level applies repeatedly in a given context, it may be omitted if its value is clearly stated initially and if its planned omission is pointed out.

3. The rules of Ref. [5: IEC 60027-3] preclude, for example, the use of the symbol dBm to indicate a reference level of power of 1 mW. This restriction is based on the rule of Sec. 7.4, which does not permit attachments to unit symbols.

8.8 Viscosity

The proper SI units for expressing values of viscosity η (also called dynamic viscosity) and values of kinematic viscosity ν are, respectively, the pascal second (Pa·s) and the meter squared per second (m^2/s) (and their decimal multiples and submultiples as appropriate). The CGS units commonly used to express values of these quantities, the poise (P) and the stoke (St), respectively [and their decimal submultiples the centipoise (cP) and the centistoke (cSt)], are not to be used; see Sec. 5.3.1 and Table 10, which gives the relations 1 P = 0.1 Pa·s and 1 St = 10^{-4} m^2/s.

8.9 Massic, volumic, areic, lineic

Reference [4: ISO 31-0] has introduced the new adjectives "massic," "volumic," "areic," and "lineic" into the English language based on their French counterparts: "massique," "volumique," "surfacique," and "linéique." They are convenient and NIST authors may wish to use them. They are equivalent, respectively, to "specific," "density," "surface . . . density," and "linear . . . density," as explained below.

(a) The adjective massic, or the adjective specific, is used to modify the name of a quantity to indicate the quotient of that quantity and its associated mass.

Examples: massic volume or specific volume: $v = V / m$

massic entropy or specific entropy: $s = S / m$

(b) The adjective *volumic* is used to modify the name of a quantity, or the term *density* is added to it, to indicate the quotient of that quantity and its associated volume.

Examples: volumic mass or (mass) density: $\rho = m / V$

volumic number or number density: $n = N / V$

Note: Parentheses around a word means that the word is often omitted.

(c) The adjective areic is used to modify the name of a quantity, or the terms surface . . . density are added to it, to indicate the quotient of that quantity (a scalar) and its associated surface area.

Examples: areic mass or surface (mass) density: $\rho_A = m / A$

areic charge or surface charge density: $\sigma = Q / A$

(d) The adjective *lineic* is used to modify the name of a quantity, or the terms *linear* . . . *density* are added to it, to indicate the quotient of that quantity and its associated length.

Examples: lineic mass or linear (mass) density: $\rho_l = m / l$

lineic electric current or linear electric current density: $A = I / b$

9 Rules and Style Conventions for Spelling Unit Names

The following eight sections give rules and style conventions related to spelling the names of units.

9.1 Capitalization

When spelled out in full, unit names are treated like ordinary English nouns. Thus the names of all units start with a lower-case letter, except at the beginning of a sentence or in capitalized material such as a title.

In keeping with this rule, the correct spelling of the name of the unit °C is "degree Celsius" (the unit "degree" begins with a lowercase "d" and the modifier "Celsius" begins with an uppercase "C" because it is the name of a person).

9.2 Plurals

Plural unit names are used when they are required by the rules of English grammar. They are normally formed regularly, for example, "henries" is the plural of henry. According to Ref. [6], the following plurals are irregular: *Singular* —lux, hertz, siemens; *Plural* —lux, hertz, siemens. (See also Sec. 9.7.)

9.3 Spelling unit names with prefixes

When the name of a unit containing a prefix is spelled out, no space or hyphen is used between the prefix and unit name (see Sec. 6.2.3).

Examples: milligram *but not:* milli-gram kilopascal *but not:* kilo-pascal

Reference [6] points out that there are three cases in which the final vowel of an SI prefix is commonly omitted: megohm (*not* megaohm), kilohm (*not* kiloohm), and hectare (*not* hectoare). In all other cases in which the unit name begins with a vowel, both the final vowel of the prefix and the vowel of the unit name are retained and both are pronounced.

9.4 Spelling unit names obtained by multiplication

When the name of a derived unit formed from other units by multiplication is spelled out, a space, which is preferred by Ref. [6] and this *Guide*, or a hyphen is used to separate the names of the individual units.

Example: pascal second or pascal-second

9.5 Spelling unit names obtained by division

When the name of a derived unit formed from other units by division is spelled out, the word "per" is used and not a solidus. (See also Secs. 6.1.7 and 9.8.)

Example: ampere per meter (A/m) *but not*: ampere/meter

9.6 Spelling unit names raised to powers

When the names of units raised to powers are spelled out, modifiers such as "squared" or "cubed" are used and are placed after the unit name.

Example: meter per second squared (m/s^2)

The modifiers "square" or "cubic" may, however, be placed before the unit name in the case of area or volume.

Examples: square centimeter (cm^2) cubic millimeter (mm^3)

ampere per square meter (A/m^2) kilogram per cubic meter (kg/m^3)

9.7 Other spelling conventions

A derived unit is usually singular in English, for example, the value 3 $m^2 \cdot K/W$ is usually spelled out as "three square meter kelvin per watt," and the value 3 $C \cdot m^2/V$ is usually spelled out as "three coulomb meter squared per volt." However, a "single" unit may be plural; for example, the value 5 kPa is spelled out as "five kilopascals," although "five kilopascal" is acceptable. If in such a single-unit case the number is less than one, the unit is always singular when spelled out; for example, 0.5 kPa is spelled out as "five-tenths kilopascal."

Note: These other spelling conventions are given for completeness; as indicated in Sec. 7.6, it is the position of this *Guide* that symbols for numbers and units should be used to express the values of quantities, *not* the spelled-out names of numbers and units. Reference [3] also requires that a symbol for a number be used whenever the value of a quantity is expressed in terms of a unit of measurement.

9.8 Unacceptability of applying mathematical operations to unit names

Because it could possibly lead to confusion, mathematical operations are not applied to unit names but only to unit symbols. (See also Secs. 6.1.7 and 9.5.)

Example: joule per kilogram or J/kg or $J \cdot kg^{-1}$ *but not*: joule/kilogram or joule·kilogram^{-1}

10 More on Printing and Using Symbols and Numbers in Scientific and Technical Documents[4]

By following the guidance given in this chapter, NIST authors can prepare manuscripts that are consistent with accepted typesetting practice.

[4] This chapter is adapted in part from Refs. [4: ISO 31-0], and [4: ISO 31-11].

10.1 Kinds of symbols

Letter symbols are of three principal kinds: (a) symbols for quantities, (b) symbols for units, and (c) symbols for descriptive terms. Quantity symbols, which are always printed in italic (that is, sloping) type, are, with few exceptions, single letters of the Latin or Greek alphabets that may have subscripts or superscripts or other identifying signs. Symbols for units, in particular those for acceptable units, have been discussed in detail in earlier portions of this *Guide*. Symbols for descriptive terms include the symbols for the chemical elements, certain mathematical symbols, and modifying superscripts and subscripts on quantity symbols.

10.1.1 Standardized quantity symbols

The use of words, acronyms, or other ad hoc groups of letters as quantity symbols should be avoided by NIST authors. For example, use the quantity symbol Z_{m} for mechanical impedance, not *MI*. In fact, there are nationally and internationally accepted symbols for literally hundreds of quantities used in the physical sciences and technology. Many of these are given in Refs. [4] and [5], and it is likely that symbols for the quantities used in most NIST publications can be found in these international standards or can readily be adapted from the symbols and principles given in these standards. Because of their international acceptance, NIST authors are urged to use the symbols of Refs. [4] and [5] to the fullest extent possible.[5]

Examples:

Ω (solid angle)	Z_{m} (mechanical impedance)
L_P (level of a power quantity)	Δ_{r} (relative mass excess)
p (pressure)	σ_{tot} (total cross section)
κ_T (isothermal compressibility)	Eu (Euler number)
E (electric field strength)	T_{N} (Néel temperature)

10.1.2 Standardized mathematical signs and symbols

As is the case for quantity symbols, most of the mathematical signs and symbols used in the physical sciences and technology are standardized. They may be found in Ref. [4: ISO 31-11] and should be used by NIST authors to the fullest possible extent.[5]

Examples:

$\wedge$	(conjunction sign, $p \wedge q$ means p and q)
$\neq$	($a \neq b$, a is not equal to b)
$\stackrel{def}{=}$	($a \stackrel{def}{=} b$, a is by definition equal to b)
$\approx$	($a \approx b$, a is approximately equal to b)
$\sim$	($a \sim b$, a is proportionally equal to b)
$\arcsin x$	(arc sine of x)
$\log_a x$	(logarithm to the base a of x)
$\mathrm{lb}\, x$	($\mathrm{lb}\, x = \log_2 x$)
$\ln x$	($\ln x = \log_e x$)
$\lg x$	($\lg x = \log_{10} x$)

10.2 Typefaces for symbols

Most word processing systems now in use at NIST are capable of producing lightface (that is, regular) or boldface letters of the Latin or Greek alphabets in both roman (upright) and italic (sloping) types. The

[5] In addition to Refs. [4] and [5], quantity symbols can also be found in ANSI/IEEE Std 280-1985, IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering. Similarly, in addition to Ref. [4: ISO 31-11], mathematical signs and symbols are also given in ANSI/IEEE Std 260.3-1993, Mathematical Signs and Symbols for Use in Physical Sciences and Technology. Another publication is the book, Symbols, Units, Nomenclature and Fundamental Constants in Physics, 1987 Revision, by E. R. Cohen and P. Giacomo, International Union of Pure and Applied Physics, SUNAMCO Commission [reprinted from Physica, Vol. 146A, Nos. 1-2, p. 1 (November, 1987)]. See also Ref [6[, Note 3.

understandability of NIST typed and typeset scientific and technical publications is facilitated if symbols are in the correct typeface. The typeface in which a symbol appears helps to define what the symbol represents. For example, irrespective of the typeface used in the surrounding text, "A" would be typed or typeset in:

— italic type for the *scalar quantity* area: A;
— roman type for the *unit* ampere: A;
— italic boldface for the *vector quantity* vector potential: $\boldsymbol{A}$.

More specifically, the three major categories of symbols found in scientific and technical publications should be typed or typeset in either italic or roman type, as follows:

— symbols for *quantities* and *variables:* italic;
— symbols for *units:* roman;
— symbols for *descriptive terms*: roman.

These rules imply that a subscript or superscript on a quantity symbol is in roman type if it is descriptive (for example, if it is a number or represents the name of a person or a particle); but it is in italic type if it represents a quantity, or is a variable such as x in E_x or an index such as i in $\sum_i x_i$ that represents a number (see Secs. 10.2.1, 10.2.3, and 10.2.4). An index that represents a number is also called a "running number" [4: ISO 31-0].

Notes:

1. The above rules also imply, for example, that μ, the symbol for the SI prefix micro (10-6), that Ω, the symbol for the SI derived unit ohm, and that F, the symbol for the SI derived unit farad, are in roman type; but they are in italic type if they represent quantities (μ, Ω, and F are the recommended symbols for the quantities magnetic moment of a particle, solid angle, and force, respectively).

2. The typeface for numbers is discussed in Sec. 10.5.1. The following four sections give examples of the proper typefaces for these three major categories.

10.2.1 Quantities and variables — italic

Symbols for quantities are italic, as are symbols for functions in general, for example, $f(x)$:

$t = 3$ s	time, s second	$T = 22$ K	T temperature, K kelvin
$r = 11$ cm	r radius, cm centimeter	$\lambda = 633$ nm	λ wavelength, nm nanometer

Constants are usually physical quantities and thus their symbols are italic; however, in general, symbols used as subscripts and superscripts are roman if descriptive (see Sec. 10.2.3):

N_{A}	Avogadro constant, A Avogadro	R	molar gas constant
θ_{D}	Debye temperature, D Debye	Z	atomic number
e	elementary charge	m_{e}	m mass, e electron

Running numbers and symbols for variables in mathematical equations are italic, as are symbols for parameters such as a and b that may be considered constant in a given context:

$$y = \sum_{i=1}^{m} x_i z_i \qquad x^2 = ay^2 = bz^2$$

Symbols for vectors are boldface italic, symbols for tensors are sans-serif bold italic, and symbols for matrices are italic:

$\boldsymbol{A}\cdot\boldsymbol{B} = \boldsymbol{C}$ (vectors) $\boldsymbol{T}$ (tensors) $A = \begin{pmatrix} a_{11} & a_{21} \\ a_{21} & a_{22} \end{pmatrix}$ (matrices)

Symbols used as subscripts and superscripts are italic if they represent quantities or variables:

C_p	p pressure	q_m	m mass	σ_Ω	Ω solid angle	ω_z	z z coordinate

10.2.2 Units— roman

The symbols for units and SI prefixes are roman:

m	meter	g	gram	L	liter
cm	centimeter	µg	microgram	mL	milliliter

10.2.3 Descriptive terms — roman

Symbols representing purely descriptive terms (for example, the chemical elements) are roman, as are symbols representing mathematical constants that never change (for example, π) and symbols representing explicitly defined functions or well defined operators (for example, $\Gamma(x)$ or div):

Chemical elements:

Ar	argon	B	boron	C	carbon

Mathematical constants, functions, and operators:

e	base of natural logarithms		Σx_i	Σ	sum of
$\exp x$	exp	exponential of	$\log_a x$	$\log_a$	logarithm to the base a of
$\mathrm{d}x/\mathrm{d}t$	d	1st derivative of	$\sin x$	sin	sine of

Symbols used as subscripts and superscripts are roman if descriptive:

$\varepsilon_0^{(\mathrm{ir})}$	ir	irrational	E_k	k	kinetic
V_m^l	m	molar, l liquid phase	μ_B	B	Bohr

10.2.4 Sample equations showing correct type

$F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2}$ $F = ma$ $pV = nRT$

$\varphi_\mathrm{B} = x_\mathrm{B} V^*_{\mathrm{m,B}} / \sum x_A V^*_{\mathrm{m},A}$ $E_\mathrm{a} = RT^2\, \mathrm{d}(\ln k)/\mathrm{d}T$ $c_1 = \lambda^{-5}/[\exp(c_2/\lambda T) - 1]$

$E = mc^2$ $\widetilde{p}_\mathrm{B} = \lambda_\mathrm{B} \lim_{p\to 0}(x_\mathrm{B} p/\lambda_\mathrm{B})$ $\dfrac{\boldsymbol{F}}{Q} = -\mathbf{grad}\, V$

10.3 Greek alphabet in roman and italic type

Table 13 shows the proper form, in both roman and italic type, of the upper-case and lower-case letters of the Greek alphabet.

Table 13. Greek alphabet in roman and italic type

Greek Letter Name	Roman		Italic	
alpha	A	α	A	α
beta	B	β	B	β
gamma	Γ	γ	$\mathit{\Gamma}$	γ
delta	Δ	δ	$\mathit{\Delta}$	δ
epsilon	E	ε	E	ε
zeta	Z	ζ	Z	ζ
eta	H	η	H	η
theta	Θ, ϴ[(a)]	θ, ϑ [(b)]	$\mathit{\Theta}$, $\mathit{\vartheta}$[(a)]	θ, ϑ [(b)]
iota	I	ι	I	ι
kappa	K	κ, ϰ [(b)]	K	κ, $\varkappa$ [(b)]
lambda	Λ	λ	$\mathit{\Lambda}$	λ
mu	M	μ	M	μ
nu	N	ν	N	ν
xi	Ξ	ξ	$\mathit{\Xi}$	ξ
omicron	O	ο	O	o
pi	Π	π, ϖ[(b)]	$\mathit{\Pi}$	π, ϖ[(b)]
rho	P	ρ	P	ρ
sigma	Σ	σ	$\mathit{\Sigma}$	σ
tau	T	τ	T	τ
upsilon	Y	υ	Y	υ
phi	Φ	φ, ϕ	$\mathit{\Phi}$	φ, ϕ
chi	X	χ	X	χ
psi	Ψ	ψ	$\mathit{\Psi}$	ψ
omega	Ω	ω	$\mathit{\Omega}$	ω

(*a*) ISO (see Ref. [4: ISO 31-0]) gives only the first of these two letters.
(*b*) ISO (see Ref. [4: ISO 31-0]) gives these two letters in the reverse order.

10.4 Symbols for the elements

The following two sections give the rules and style conventions for the symbols for the elements.

10.4.1 Typeface and punctuation for element symbols

Symbols for the elements are normally printed in roman type without regard to the type used in the surrounding text (see Sec. 10.2.3). They are not followed by a period unless at the end of a sentence.

10.4.2 Subscripts and superscripts on element symbols

The nucleon number (mass number) of a nuclide is indicated in the left superscript position: $^{28}\mathrm{Si}$.

The number of atoms in a molecule of a particular nuclide is shown in the right subscript position: $^{1}\mathrm{H}_2$.

The proton number (atomic number) is indicated in the left subscript position: $_{29}\mathrm{Cu}$.

The state of ionization or excitation is indicated in the right superscript position, some examples of which are as follows:

State of ionization: Ba^{++}

$Co(NO_2)_6^{---}$ or $Co(NO_2)_6^{3-}$ or $[Co(NO_2)_6]^{3-}$

Electronic excited state: Ne*, CO*

Nuclear excited state: $^{15}N^*$ or $^{15}N^m$

10.5 Printing numbers

The following three sections give rules and style conventions related to the printing of numbers.

10.5.1 Typeface for numbers

Arabic numerals expressing the numerical values of quantities (see Sec. 7.6) are generally printed in lightface (that is, regular) roman type irrespective of the type used for the surrounding text. Arabic numerals other than numerical values of quantities may be printed in lightface or bold italics, or in bold roman type, but lightface roman type is usually preferred.

10.5.2 Decimal sign or marker

The recommended decimal sign or marker for use in the United States is the dot on the line [3, 6]. For numbers less than one, a zero is written before the decimal marker. For example, 0.25 s is the correct form, *not* .25 s.

10.5.3 Grouping digits

Because the comma is widely used as the decimal marker outside the United States, it should not be used to separate digits into groups of three. Instead, digits should be separated into groups of three, counting from the decimal marker towards the left and right, by the use of a thin, fixed space. However, this practice is not usually followed for numbers having only four digits on either side of the decimal marker except when uniformity in a table is desired.

Examples:	76 483 522	*but not:*	76,483,522
	43 279.168 29	*but not:*	43,279.168 29
	8012 or 8 012	*but not:*	8,012
	0.491 722 3	*is highly preferred to:*	0.4917223
	0.5947 or 0.594 7	*but not:*	0.59 47
	8012.5947 or 8 012.594 7	*but not:*	8 012.5947 or 8012.594 7

Note: The practice of using a space to group digits is not usually followed in certain specialized applications, such as engineering drawings and financial statements.

10.5.4 Multiplying numbers

When the dot is used as the decimal marker as in the United States, the preferred sign for the multiplication of numbers or values of quantities is a cross (that is, multiplication sign) (×), not a half-high (that is, centered) dot (·).

Examples:	25×60.5	*but not:*	$25 \cdot 60.5$
	$53\ \mathrm{m/s} \times 10.2\ \mathrm{s}$	*but not:*	$53\ \mathrm{m/s} \cdot 10.2\ \mathrm{s}$
	$15 \times 72\ \mathrm{kg}$	*but not:*	$15 \cdot 72\ \mathrm{kg}$

Notes:

1. When the comma is used as the decimal marker, the preferred sign for the multiplication of numbers is the half-high dot. However, even when the comma is so used, this Guide prefers the cross for the multiplication of values of quantities.

2. The multiplication of quantity symbols (or numbers in parentheses or values of quantities in parentheses) may be indicated in one of the following ways: ab, $a\ b$, $a \cdot b$, $a \times b$.

Appendix A. Definitions of the SI Base Units

A.1 Introduction

The following definitions of the SI base units are taken from Refs. [1, 2]; it should be noted that SI derived units are uniquely defined only in terms of SI base units; for example, $1\ \mathrm{V} = 1\ \mathrm{m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}}$.

A.2 **Meter** (17th CGPM, 1983)

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 *of a second.*

A.3 **Kilogram** (3d CGPM, 1901)

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

A.4 **Second** (13th CGPM, 1967)

The second is the duration of 9 192 631 770 *periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-*133 *atom.*

A.5 **Ampere** (9th CGPM, 1948)

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 *meter apart in vacuum, would produce between these conductors a force equal to* 2×10^{-7} *newton per meter of length.*

A.6 **Kelvin** (13th CGPM, 1967)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 *of the thermodynamic temperature of the triple point of water.*

A.7 **Mole** (14th CGPM, 1971)

1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

In the definition of the mole, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to.

Note: This definition specifies at the same time the nature of the quantity whose unit is the mole.

A.8 **Candela** (16th CGPM, 1979)

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of (1/683) watt per steradian.

Appendix B. Conversion Factors[6]

B.1 Introduction

Sections B.8 and B.9 give factors for converting values of quantities expressed in various units—predominantly units outside the SI that are unacceptable for use with it—to values expressed either in (a) SI units, (b) units that are accepted for use with the SI (especially units that better reflect the nature of the unconverted units), (c) units formed from such accepted units and SI units, or (d) decimal multiples or submultiples of the units of (a) to (c) that yield numerical values of convenient magnitudes.

An example of (d) is the following: the values of quantities expressed in ångströms, such as the wavelengths of visible laser radiations, are usually converted to values expressed in nanometers, not meters. More generally, if desired, one can eliminate powers of 10 that appear in converted values as a result of using the conversion factors (or simply factors for brevity) of Secs. B.8 and B.9 by selecting an appropriate SI prefix (see Sec. B.3).

B.2 Notation

The factors given in Secs. B.8 and B.9 are written as a number equal to or greater than 1 and less than 10, with 6 or fewer decimal places. The number is followed by the letter E, which stands for exponent, a plus (+) or minus (–) sign, and two digits that indicate the power of 10 by which the number is multiplied.

Examples: 3.523 907 E–02 means $3.523\,907 \times 10^{-2} = 0.035\,239\,07$

3.386 389 E+03 means $3.386\,389 \times 10^{3} = 3386.389$

A factor in boldface is exact. All other factors have been rounded to the significant digits given in accordance with accepted practice (see Secs. 7.9, B.7.2, and Refs. [4: ISO 31-0] and [6]). Where less than six digits after the decimal place are given, the unit does not warrant a greater number of digits in its conversion. However, for the convenience of the user, this practice is not followed for all such units, including the cord, cup, quad, and teaspoon.

B.3 Use of conversion factors

Each entry in Secs. B.8 and B.9 is to be interpreted as in these two examples:

To convert from	to	Multiply by	
atmosphere, standard (atm)	pascal (Pa)	**1.01325**	**E+05**
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	2.831 685	E–02

means 1 atm = 101 325 Pa (exactly);
$1\ ft^3/s = 0.028\,316\,85\ m^3/s$.

Thus to express, for example, the pressure $p = 11.8$ standard atmospheres (atm) in pascals (Pa), write $p = 11.8\ \text{atm} \times 101\,325\ \text{Pa/atm}$ and obtain the converted numerical value $11.8 \times 101\,325 = 1\,195\,635$ and the converted value $p = 1.20$ MPa.

[6] This appendix is essentially the same as Appendix B of the 1995 Edition. That appendix was significantly revised version of Appendix C of the 1991 Edition, which was reprinted from ANSI/IEEE Std 268-1982, *American National Standard Metric Practice*, ©1982 by the Institute of Electrical and Electronics Engineers, Inc., with the permission of the IEEE. The origin of this material is E. A. Mechtly, *The International System of Units — Physical Constants and Conversion Factors*, NASA SP-7012, Second Revision, National Aeronautics and Space Administration (U.S. Government Printing Office, Washington, DC, 1973).

Notes:

1. Guidance on rounding converted numerical values of quantities is given in Sec. B.7.2.

2. If the value of a quantity is expressed in a unit of the center column of Sec. B.8 or B.9 and it is necessary to express it in the corresponding unit of the first column, *divide* by the factor.

   The factors for derived units not included in Secs. B.8 and B.9 can readily be found from the factors given.

Examples: To find the factor for converting values in lb·ft/s to values in kg·m/s, obtain from Sec. B.8 or B.9

1 lb = 4.535 924 E−01 kg
1 ft = **3.048 E−01** m

and substitute these values into the unit lb·ft/s to obtain

1 lb·ft/s = 0.453 592 4 kg × 0.3048 m/s
= 0.138 255 0 kg·m/s

and the factor is 1.382 550 E−01.

To find the factor for converting values in (avoirdupois) oz·in^2 to values in kg·m^2, obtain from Sec. B.8 or B.9

1 oz = 2.834 952 E−02 kg
1 in^2 = **6.4516 E−04** m^2

and substitute these values into the unit oz·in^2 to obtain

1 oz·in^2 = 0.028 349 52 kg × 0.000 645 16 m^2
= 0.000 018 289 98 kg·m^2

and the factor is 1.828 998 E−05.

B.4 Organization of entries and style

In Sec. B.8 the units for which factors are given are listed alphabetically, while in Sec B.9 the same units are listed alphabetically within the following alphabetized list of kinds of quantities and fields of science:

ACCELERATION
ANGLE
AREA AND SECOND MOMENT
OF AREA
CAPACITY (see VOLUME)
DENSITY (that is, MASS DENSITY)
(see MASS DIVIDED BY VOLUME)
ELECTRICITY and MAGNETISM
ENERGY (includes WORK)
ENERGY DIVIDED BY AREA TIME
FLOW (see MASS DIVIDED BY TIME
or VOLUME DIVIDED BY TIME)
FORCE
FORCE DIVIDED BY LENGTH
HEAT
Available Energy
Coefficient of Heat Transfer
Density of Heat
Density of Heat Flow Rate
Fuel Consumption
Heat Capacity and Entropy
Heat Flow Rate
Specific Heat Capacity and Specific Entropy
Thermal Conductivity
Thermal Diffusivity
Thermal Insulance

FORCE DIVIDED BY AREA
(see PRESSURE)
LENGTH
LIGHT
MASS and MOMENT OF INERTIA
MASS DENSITY (see MASS DIVIDED BY VOLUME)
MASS DIVIDED BY AREA
MASS DIVIDED BY CAPACITY
(see MASS DIVIDED BY VOLUME)
MASS DIVIDED BY LENGTH
MASS DIVIDED BY TIME
(includes FLOW)
MASS DIVIDED BY VOLUME
(includes MASS DENSITY and MASS CONCENTRATION)
MOMENT OF FORCE or TORQUE
MOMENT OF FORCE or TORQUE, DIVIDED BY LENGTH
PERMEABILITY
Thermal Resistance
Thermal Resistivity
POWER
PRESSURE or STRESS (FORCE DIVIDED BY AREA)
RADIOLOGY
SPEED (see VELOCITY)
STRESS (see PRESSURE)
TEMPERATURE
TEMPERATURE INTERVAL
TIME
TORQUE (see MOMENT OF FORCE)
VELOCITY (includes SPEED)
VISCOSITY, DYNAMIC
VISCOSITY, KINEMATIC
VOLUME (includes CAPACITY)
VOLUME DIVIDED BY TIME
(includes FLOW)
WORK (see ENERGY)

In Secs. B.8 and B.9, the units in the left-hand columns are written as they are often used customarily; the rules and style conventions recommended in this *Guide* are not necessarily observed. Further, many are obsolete and some are not consistent with good technical practice. The corresponding units in the center columns are, however, written in accordance with the rules and style conventions recommended in this *Guide*.

B.5 Factor for converting motor vehicle efficiency

The efficiency of motor vehicles in the United States is commonly expressed in miles per U.S. gallon, while in most other countries it is expressed in liters per one hundred kilometers. To convert fuel economy stated in miles per U.S. gallon to fuel consumption expressed in L/(100 km), divide 235.215 by the numerical value of the stated fuel economy. Thus 24 miles per gallon corresponds to 9.8 L/(100 km).

B.6 U.S. survey foot and mile

The U.S. Metric Law of 1866 gave the relationship 1 m = 39.37 in (in is the unit symbol for the inch). From 1893 until 1959, the yard was defined as being exactly equal to (3600/3937) m, and thus the foot was defined as being exactly equal to (1200/3937) m.

In 1959 the definition of the yard was changed to bring the U.S. yard and the yard used in other countries into agreement; sec Ref. [7: FR 1959]. Since then the yard has been defined as exactly equal to 0.9144 m, and thus the foot has been defined as exactly equal to 0.3048 m. At the same time it was decided that any data expressed in feet derived from geodetic surveys within the United States would continue to bear the relationship as defined in 1893, namely, 1 ft = (1200/3937) m (ft is the unit symbol for the foot). The name of this foot is "U.S. survey foot," while the name of the new foot defined in 1959 is "international foot." The two are related to each other through the expression 1 international foot = 0.999 998 U.S. survey foot exactly.

In Secs. B.8 and B.9, the factors given are based on the international foot unless otherwise indicated. Users of this *Guide* will also find the following summary of exact relationships helpful, where for convenience in this section, the symbols *ft* and *mi*, that is, ft and mi in italic type, indicate that it is the *U.S. survey foot* or *U.S. survey mile* that is meant rather than the international foot (ft) or international mile (mi), and where rd is the unit symbol for the rod and fur is the unit symbol for the furlong.

1 *ft* = (1200/3937) m
1 ft = 0.3048 m
1 ft = 0.999 998 *ft*
1 rd, pole, or perch = 16 ½ ft
40 rd = 1 fur = 660 *ft*
8 fur = 1 U.S. survey mile (also called "statute mile") = 1 *mi* = 5280 *ft*
1 fathom = 6 *ft*
1 international mile = 1 mi = 5280 ft
272 1/4 ft^2 = 1 rd^2
160 rd^2 = 1 acre = 43 560 ft^2
640 acre = 1 mi^2

B.7 Rules for rounding numbers and converted numerical values of quantities

Rules for rounding numbers are discussed in Refs. [4: ISO 31-0] and [6]; the latter reference also gives rules for rounding the converted numerical values of quantities whose values expressed in units that are not accepted for use with the SI (primarily customary or inch-pound units) are converted to values expressed in acceptable units. This *Guide* gives the principal rules for rounding numbers in Sec. B.7.1, and the basic principle for rounding converted numerical values of quantities in Sec. B.7.2. The cited references should be consulted for additional details.

B.7.1 Rounding numbers

To replace a number having a given number of digits with a number (called the rounded number) having a smaller number of digits, one may follow these rules:

1. If the digits to be discarded begin with a digit less than 5, the digit preceding the 5 is not changed.

Example: 6.974 951 5 rounded to 3 digits is 6.97

2. If the digits to be discarded begin with a 5 and at least one of the following digits is greater than 0, the digit preceding the 5 is increased by 1.

Examples: 6.974 951 5 rounded to 2 digits is 7.0
6.974 951 5 rounded to 5 digits is 6.9750

3. If the digits to be discarded begin with a 5 and all of the following digits are 0, the digit preceding the 5 is unchanged if it is even and increased by 1 if it is odd. (Note that this means that the final digit is always even.)

Examples: 6.974 951 5 rounded to 7 digits is 6.974 952
6.974 950 5 rounded to 7 digits is 6.974 950

B.7.2 Rounding converted numerical values of quantities

The use of the factors given in Secs. B.8 and B.9 to convert values of quantities was demonstrated in Sec. B.3. In most cases the product of the unconverted numerical value and the factor will be a numerical value with a number of digits that exceeds the number of significant digits (see Sec. 7.9) of the unconverted numerical value. Proper conversion procedure requires rounding this converted numerical value to the number of significant digits that is consistent with the maximum possible rounding error of the unconverted numerical value.

Example: To express the value l = 36 ft in meters, use the factor **3.048 E−01** from Sec. B.8 or Sec. B.9 and write

$$l = 36 \text{ ft} \times 0.3048 \text{ m/ft} = 10.9728 \text{ m} = 11.0 \text{ m}.$$

The final result, $l = 11.0$ m, is based on the following reasoning: The numerical value “36” has two significant digits, and thus a relative maximum possible rounding error (abbreviated RE in this *Guide* for simplicity) of $\pm$ 0.5/36 = $\pm$ 1.4 %, because it could have resulted from rounding the number 35.5, 36.5, or any number between 35.5 and 36.5. To be consistent with this RE, the converted numerical value “10.9728” is rounded to 11.0 or three significant digits because the number 11.0 has an RE of $\pm$ 0.05/11.0 = $\pm$ 0.45 %. Although this $\pm$ 0.45 % RE is one-third of the $\pm$ 1.4 % RE of the unconverted numerical value “36,” if the converted numerical value “10.9728” had been rounded to 11 or two significant digits, information contained in the unconverted numerical value “36” would have been lost. This is because the RE of the numerical value “11” is $\pm$ 0.5/11 = $\pm$ 4.5 %, which is three times the $\pm$ 1.4 % RE of the unconverted numerical value “36.” This example therefore shows that when selecting the number of digits to retain in the numerical value of a converted quantity, one must often choose between discarding information or providing unwarranted information. Consideration of the end use of the converted value can often help one decide which choice to make.

Note: Consider that one had been told initially that the value $l = 36$ ft had been rounded to the nearest inch. Then in this case, since l is known to within $\pm$ 1 in, the RE of the numerical value “36” is $\pm$ 1 in/(36 ft $\times$ 12 in/ft) = $\pm$ 0.23 %. Although this is less than the $\pm$ 0.45 % RE of the number 11.0, it is comparable to it. Therefore, the result $l = 11.0$ m is still given as the converted value. (Note that the numerical value “10.97” would give excessive unwarranted information because it has an RE that is one-fifth of $\pm$ 0.23 %.)

B.8 Factors for units listed alphabetically

Caution: The units listed in column 1 are in general not to be used in NIST publications, with the exception of those few in italic type.

Factors in **boldface** are exact

To convert from	to	Multiply by	
abampere	ampere (A)	**1.0**	**E+01**
abcoulomb	coulomb (C)	**1.0**	**E+01**
abfarad	farad (F)	**1.0**	**E+09**
abhenry	henry (H)	**1.0**	**E−09**
abmho	siemens (S)	**1.0**	**E+09**
abohm	ohm (Ω)	**1.0**	**E−09**
abvolt	volt (V)	**1.0**	**E−08**
acceleration of free fall, standard (g_n)	meter per second squared (m / s^2)	**9.806 65**	**E+00**
acre (based on U.S. survey foot)[7]	square meter (m^2)	4.046 873	E+03
acre foot (based on U.S. survey foot)[7]	cubic meter (m^3)	1.233 489	E+03
ampere hour (A·h)	coulomb (C)	**3.6**	**E+03**
ångström (Å)	meter (m)	**1.0**	**E−10**
ångström (Å)	nanometer (nm)	**1.0**	**E−01**
are (a)	square meter (m^2)	**1.0**	**E+02**
astronomical unit (ua)	meter (m)	1.495 979	E+11
atmosphere, standard (atm)	pascal (Pa)	**1.013 25**	**E+05**
atmosphere, standard (atm)	kilopascal (kPa)	**1.013 25**	**E+02**
atmosphere, technical (at)[8]	pascal (Pa)	**9.806 65**	**E+04**
atmosphere, technical (at)[8]	kilopascal (kPa)	**9.806 65**	**E+01**
bar (bar)	pascal (Pa)	**1.0**	**E+05**
bar (bar)	kilopascal (kPa)	**1.0**	**E+02**
barn (b)	square meter (m^2)	**1.0**	**E−28**
barrel [for petroleum, 42 gallons (U.S.)](bbl)	cubic meter (m^3)	1.589 873	E−01
barrel [for petroleum, 42 gallons (U.S.)](bbl)	liter (L)	1.589 873	E+02
biot (Bi)	ampere (A)	**1.0**	**E+01**
British thermal unit$_{IT}$ (Btu$_{IT}$)[9]	joule (J)	1.055 056	E+03
British thermal unit$_{th}$ (Btu$_{IT}$)[9]	joule (J)	1.054 350	E+03
British thermal unit (mean) (Btu)	joule (J)	1.055 87	E+03
British thermal unit (39 °F) (Btu)	joule (J)	1.059 67	E+03
British thermal unit (59 °F) (Btu)	joule (J)	1.054 80	E+03
British thermal unit (60 °F) (Btu)	joule (J)	1.054 68	E+03
British thermal unit$_{IT}$ foot per hour square foot degree Fahrenheit [Btu$_{IT}$·ft/(h·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	1.730 735	E+00
British thermal unit$_{th}$ foot per hour square foot degree Fahrenheit [Btu$_{th}$·ft/(h·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	1.729 577	E+00
British thermal unit$_{IT}$ inch per hour square foot degree Fahrenheit [Btu$_{IT}$·in/(h·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	1.442 279	E−01
British thermal unit$_{th}$ inch per hour square foot degree Fahrenheit [Btu$_{th}$·in/(h·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	1.441 314	E−01
British thermal unit$_{IT}$ inch per second square foot degree Fahrenheit [Btu$_{IT}$·in/(s·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	5.192 204	E+02

[7] For remarks on U.S. survey foot, see Sec. B.6.

[8] One technical atmosphere equals one kilogram-force per square centimeter (1 at = 1 kgf/cm2).

[9] The Fifth International Conference on the Properties of Steam (London, July 1956) defined the International Table calorie as 4.1868 J. Therefore, the exact conversion factor for the International Table Btu is 1.055 055 852 62 kJ. Note that the notation for International Table used in this listing is subscript "IT." Similarily, the notation for thermochemical is subscript "th." Further, the thermochemical Btu, Btuth, is based on the thermochemical calorie, calth, where calth = 4.184 J exactly.

To convert from	to	Multiply by
British thermal unit$_{th}$ inch per second square foot degree Fahrenheit [Btu$_{th}$·in/(s·ft^2·°F)]	watt per meter kelvin [W / (m · K)]	5.188 732 E+02
British thermal unit$_{IT}$ per cubic foot (Btu$_{IT}$/ft^3)	joule per cubic meter (J / m^3)	3.725 895 E+04
British thermal unit$_{th}$ per cubic foot (Btu$_{th}$/ft^3)	joule per cubic meter (J / m^3)	3.723 403 E+04
British thermal unit$_{IT}$ per degree Fahrenheit (Btu$_{IT}$/°F)	joule per kelvin (J / k)	1.899 101 E+03
British thermal unit$_{th}$ per degree Fahrenheit (Btu$_{th}$/°F)	joule per kelvin (J / k)	1.897 830 E+03
British thermal unit$_{IT}$ per degree Rankine (Btu$_{IT}$ / °R)	joule per kelvin (J / k)	1.899 101 E+03
British thermal unit$_{th}$ per degree Rankine (Btu$_{th}$ / °R)	joule per kelvin (J / K)	1.897 830 E+03
British thermal unit$_{IT}$ per hour (Btu$_{IT}$/h)	watt (W)	2.930 711 E−01
British thermal unit$_{th}$ per hour (Btu$_{th}$/h)	watt (W)	2.928 751 E−01
British thermal unit$_{IT}$ per hour square foot degree Fahrenheit [Btu$_{IT}$ / (h·ft^2·°F)]	watt per square meter kelvin [W / (m^2 · K)]	5.678 263 E+00
British thermal unit$_{th}$ per hour square foot degree Fahrenheit [Btu$_{th}$ / (h·ft^2·°F)]	watt per square meter kelvin [W / (m^2 · K)]	5.674 466 E+00
British thermal unit$_{th}$ per minute (Btu$_{th}$ / min)	watt (W)	1.757 250 E+01
British thermal unit$_{IT}$ per pound (Btu$_{IT}$ / lb)	joule per kilogram (J / kg)	**2.326 E+03**
British thermal unit$_{th}$ per pound (Btu$_{th}$ / lb)	joule per kilogram (J / kg)	2.324 444 E+03
British thermal unit$_{IT}$ per pound degree Fahrenheit [Btu$_{IT}$ / (lb·°F)]	joule per kilogram kelvin (J / (kg · K)]	**4.1868 E+03**
British thermal unit$_{th}$ per pound degree Fahrenheit [Btu$_{th}$ / (lb·°F)]	joule per kilogram kelvin [J / (kg · K)]	**4.184 E+03**
British thermal unit$_{IT}$ per pound degree Rankine [Btu$_{IT}$ / (lb·°R)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868 E+03**
British thermal unit$_{t}$h per pound degree Rankine [Btu$_{th}$ / (lb·°R)]	joule per kilogram kelvin [J / (kg · K)]	**4.184 E+03**
British thermal unit$_{IT}$ per second (Btu$_{IT}$ / s)	watt (W)	1.055 056 E+03
British thermal unit$_{th}$ per second (Btu$_{th}$ / s)	watt (W)	1.054 350 E+03
British thermal unit$_{IT}$ per second square foot degree Fahrenheit [Btu$_{IT}$ / (s · ft^2·°F)]	watt per square meter kelvin [W/(m^2 · K)]	2.044 175 E+04
British thermal unit$_{th}$ per second square foot degree Fahrenheit [Btu$_{th}$ / (s · ft^2·°F)]	watt per square meter kelvin [W/(m^2 · K)]	2.042 808 E+04
British thermal unit$_{IT}$ per square foot (Btu$_{IT}$ / ft^2)	joule per square meter (J / m^2)	1.135 653 E+04
British thermal unit$_{th}$ per square foot (Btu$_{th}$ / ft^2)	joule per square meter (J / m^2)	1.134 893 E+04
British thermal unit$_{IT}$ per square foot hour [(Btu$_{IT}$ / (ft^2 · h)]	watt per square meter (W / m^2)	3.154 591 E+00
British thermal unit$_{th}$ per square foot hour [Btu$_{th}$ / (ft^2 · h)]	watt per square meter (W / m^2)	3.152 481 E+00
British thermal unit$_{t}$h per square foot minute [Btu$_{th}$ / (ft^2 · min)]	watt per square meter (W / m^2)	1.891 489 E+02
British thermal unit$_{IT}$ per square foot second [(Btu$_{IT}$ / (ft^2 · s)]	watt per square meter (W / m^2)	1.135 653 E+04

To convert from	to	Multiply by	
British thermal unit$_{th}$ per square foot second [Btu_{th} / ($ft^2 \cdot s$)]	watt per square meter (W / m^2)	1.134 893	E+04
British thermal unit$_{th}$ per square inch second [Btu_{th} /($in^2 \cdot s$)]	watt per square meter (W / m^2)	1.634 246	E+06
bushel (U.S.) (bu)	cubic meter (m^3)	3.523 907	E−02
bushel (U.S.) (bu)	liter (L)	3.523 907	E+01
calorie$_{IT}$ (cal$_{IT}$)[10]	joule (J)	**4.1868**	**E+00**
calorie$_{th}$ (cal$_{th}$)[10]	joule (J)	**4.184**	**E+00**
calorie (cal) (mean)	joule (J)	4.190 02	E+00
calorie (15 °C) (cal$_{15}$)	joule (J)	4.185 80	E+00
calorie (20 °C) (cal$_{20}$)	joule (J)	4.181 90	E+00
calorie$_{IT}$, kilogram (nutrition)[11]	joule (J)	**4.1868**	**E+03**
calorie$_{th}$, kilogram (nutrition)[11]	joule (J)	**4.184**	**E+03**
calorie (mean), kilogram (nutrition)[11]	joule (J)	4.190 02	E+03
calorie$_{th}$ per centimeter second degree Celsius [cal$_{th}$ / (cm · s · °C)]	watt per meter kelvin [W / (m · K)]	**4.184**	**E+02**
calorie$_{IT}$ per gram (cal$_{IT}$ / g)	joule per kilogram (J / kg)	**4.1868**	**E+03**
calorie$_{th}$ per gram (cal$_{th}$ / g)	joule per kilogram (J / kg)	**4.184**	**E+03**
calorie$_{IT}$ per gram degree Celsius [cal$_{IT}$ / (g·°C)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram degree Celsius [cal$_{th}$ / (g·°C)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
calorie$_{IT}$ per gram kelvin [cal$_{IT}$ / (g·K)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram kelvin [cal$_{th}$ / (g·K)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
calorie$_{th}$ per minute (cal$_{th}$ / min)	watt (W)	6.973 333	E−02
calorie$_{th}$ per second (cal$_{th}$ / s)	watt (W)	**4.184**	**E+00**
calorie$_{th}$ per square centimeter (cal$_{th}$ / cm^2)	joule per square meter (J / m^2)	**4.184**	**E+04**
calorie$_{th}$ per square centimeter minute [cal$_{th}$ / ($cm^2 \cdot$ min)]	watt per square meter (W / m^2)	6.973 333	E+02
calorie$_{th}$ per square centimeter second cal$_{th}$ / ($cm^2 \cdot s$)]	watt per square meter (W / m^2)	**4.184**	**E+04**
candela per square inch (cd / in^2)	candela per square meter (cd / m^2)	1.550 003	E+03
carat, metric	kilogram (kg)	**2.0**	**E−04**
carat, metric	gram (g)	**2.0**	**E−01**
centimeter of mercury (0 °C)[12]	pascal (Pa)	1.333 22	E+03
centimeter of mercury (0 °C)[12]	kilopascal (kPa)	1.333 22	E+00
centimeter of mercury, conventional (cmHg)[12]	pascal (Pa)	1.333 224	E+03
centimeter of mercury, conventional (cmHg)[12]	kilopascal (kPa)	1.333 224	E+00
centimeter of water (4 °C)[12]	pascal (Pa)	9.806 38	E+01
centimeter of water, conventional (cmH_2O)[12]	pascal (Pa)	**9.806 65**	**E+01**
centipoise (cP)	pascal second (Pa·s)	**1.0**	**E−03**
centistokes (cSt)	meter squared per second (m^2/s)	**1.0**	**E−06**
chain (based on U.S. survey foot) (ch)[7]	meter (m)	2.011 684	E+01
circular mil	square meter (m^2)	5.067 075	E−10

[10] The small calorie or gram calorie approximates the energy needed to increase the temperature of 1 gram of water by 1 °C. Subscripts "$_{IT}$" and "$_{th}$" refer to International Table and thermochemical calories, respectively; see footnote 9.

[11] The kilogram calorie or "large calorie" is an obsolete term used for the kilocalorie, which is the calorie used to express the energy content of foods. However, in practice, the prefix "kilo" is usually omitted.

[12] Conversion factors for mercury manometer pressure units are calculated using the standard value for the acceleration of gravity and the density of mercury at the stated temperature. Additional digits are not justified because the definitions of the units do not take into account the compressibility of mercury or the change in density caused by the revised practical temperature scale, ITS-90. Similar comments also apply to water manometer pressure units. Conversion factors for conventional mercury and water manometer pressure units are based on Ref. [4: ISO 31-3].

To convert from	to	Multiply by
circular mil	square millimeter (mm^2)	5.067 075 E−04
clo	square meter kelvin per watt ($m^2 \cdot K / W$)	1.55 E−01
cord (128 ft^3)	cubic meter (m^3)	3.624 556 E+00
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E−02
cubic foot per minute (ft^3 / min)	cubic meter per second (m^3 / s)	4.719 474 E−04
cubic foot per minute (ft^3 / min)	liter per second (L/s)	4.719 474 E−01
cubic foot per second (ft^3 / s)	cubic meter per second (m^3 / s)	2.831 685 E−02
cubic inch (in^3)[13]	cubic meter (m^3)	1.638 706 E−05
cubic inch per minute (in^3 / min)	cubic meter per second (m^3 / s)	2.731 177 E−07
cubic mile (mi^3)	cubic meter (m^3)	4.168 182 E+09
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E−01
cubic yard per minute (yd^3 / min)	cubic meter per second (m^3 / s)	1.274 258 E−02
cup (U.S.)	cubic meter (m^3)	2.365 882 E−04
cup (U.S.)	liter (L)	2.365 882 E−01
cup (U.S.)	milliliter (mL)	2.365 882 E+02
curie (Ci)	becquerel (Bq)	**3.7 E+10**
darcy[14]	meter squared (m^2)	9.869 233 E−13
day (d)	second (s)	**8.64 E+04**
day (sidereal)	second (s)	8.616 409 E+04
debye (D)	coulomb meter (C · m)	3.335 641 E−30
degree (angle) (°)	radian (rad)	1.745 329 E−02
degree Celsius (temperature) (°C)	kelvin (K)	$T/\text{K} = t/{^\circ}\text{C} + \mathbf{273.15}$
degree Celsius (temperature interval) (°C)	kelvin (K)	**1.0 E+00**
degree centigrade (temperature)[15]	degree Celsius (°C)	$t/{^\circ}\text{C} \approx t/\text{deg. cent.}$
degree centigrade (temperature interval)[15]	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (temperature) (°F)	degree Celsius (°C)	$t/{^\circ}\text{C} = (t/{^\circ}\text{F} - \mathbf{32})/\mathbf{1.8}$
degree Fahrenheit (temperature) (°F)	kelvin (K)	$T/\text{K} = (t/{^\circ}\text{F} + \mathbf{459.67})/\mathbf{1.8}$
degree Fahrenheit (temperature interval)(°F)	degree Celsius (°C)	5.555 556 E−01
degree Fahrenheit (temperature interval) (°F)	kelvin (K)	5.555 556 E−01
degree Fahrenheit hour per British thermal unit$_{IT}$ (°F · h/Btu$_{IT}$)	kelvin per watt (K/W)	1.895 634 E+00
degree Fahrenheit hour per British thermal unit$_{th}$ (°F·h / Btu$_{th}$)	kelvin per watt (K / W)	1.896 903 E+00
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ (°F · h · ft^2 / Btu$_{IT}$)	square meter kelvin per watt (m^2 · K / W)	1.761 102 E−01
degree Fahrenheit hour square foot per British thermal unit$_{th}$ (°F · h · ft^2 / Btu$_{th}$)	square meter kelvin per watt (m^2 · K / W)	1.762 280 E−01
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ inch [°F · h · ft^2 / (Btu$_{IT}$ · in)]	meter kelvin per watt (m · K / W)	6.933 472 E+00
degree Fahrenheit hour square foot per British thermal unit$_{th}$ inch [°F · h · ft^2 / (Btu$_{th}$ · in)]	meter kelvin per watt (m · K / W)	6.938 112 E+00
degree Fahrenheit second per British thermal unit$_{IT}$ (°F · s / Btu$_{IT}$)	kelvin per watt (K / W)	5.265 651 E−04
degree Fahrenheit second per British thermal unit$_{th}$ (°F · s / Btu$_{th}$)	kelvin per watt (K / W)	5.269 175 E−04
degree Rankine (°R)	kelvin (K)	$T/\text{K} = (T/{^\circ}\text{R}) / \mathbf{1.8}$

[13] The exact conversion factor is 1.638 706 4 E−05.
[14] The darcy is a unit for expressing the permeability of porous solids, not area.
[15] The centigrade temperature scale is obsolete; the degree centigrade is only approximately equal to the degree Celsius.

To convert from	to	Multiply by	
degree Rankine (temperature interval) (°R)	kelvin (K)	5.555 556	E−01
denier	kilogram per meter (kg / m)	1.111 111	E−07
denier	gram per meter (g / m)	1.111 111	E−04
dyne (dyn)	newton (N)	**1.0**	**E−05**
dyne centimeter (dyn·cm)	newton meter (N · m)	**1.0**	**E−07**
dyne per square centimeter (dyn / cm^2)	pascal (Pa)	**1.0**	**E−01**
electronvolt (eV)	joule (J)	1.602 176	E−19
EMU of capacitance (abfarad)	farad (F)	**1.0**	**E+09**
EMU of current (abampere)	ampere (A)	**1.0**	**E+01**
EMU of Electric potential (abvolt)	volt (V)	**1.0**	**E−08**
EMU of inductance (abhenry)	henry (H)	**1.0**	**E−09**
EMU of resistance (abohm)	ohm (Ω)	**1.0**	**E−09**
erg (erg)	joule (J)	**1.0**	**E−07**
erg per second (erg / s)	watt (W)	**1.0**	**E−07**
erg per square centimeter second [erg / (cm^2 · s)]	watt per square meter (W / m^2)	**1.0**	**E−03**
ESU of capacitance (statfarad)	farad (F)	1.112 650	E−12
ESU of current (statampere)	ampere (A)	3.335 641	E−10
ESU of Electric potential (statvolt)	volt (V)	2.997 925	E+02
ESU of inductance (stathenry)	henry (H)	8.987 552	E+11
ESU of resistance (statohm)	ohm (Ω)	8.987 552	E+11
faraday (based on carbon 12)	coulomb (C)	9.648 534	E+04
fathom (based on U.S. survey foot)[7]	meter (m)	1.828 804	E+00
fermi	meter (m)	**1.0**	**E−15**
fermi	femtometer (fm)	**1.0**	**E+00**
fluid ounce (U.S.) (fl oz)	cubic meter (m^3)	2.957 353	E−05
fluid ounce (U.S.) (fl oz)	milliliter (mL)	2.957 353	E+01
foot (ft)	meter (m)	**3.048**	**E−01**
foot (U.S. survey) (ft)[7]	meter (m)	3.048 006	E−01
footcandle	lux (lx)	1.076 391	E+01
footlambert	candela per square meter (cd / m^2)	3.426 259	E+00
foot of mercury, conventional (ftHg)[12]	pascal (Pa)	4.063 666	E+04
foot of mercury, conventional (ftHg)[12]	kilopascal (kPa)	4.063 666	E+01
foot of water (39.2 °F)[12]	pascal (Pa)	2.988 98	E+03
foot of water (39.2 °F)[12]	kilopascal (kPa)	2.988 98	E+00
foot of water, conventional (ftH_2O)[12]	pascal (Pa)	2.989 067	E+03
foot of water, conventional (ftH_2O)[12]	kilopascal (kPa)	2.989 067	E+00
foot per hour (ft / h)	meter per second (m / s)	8.466 667	E−05
foot per minute (ft / min)	meter per second (m / s)	**5.08**	**E−03**
foot per second (ft / s)	meter per second (m / s)	**3.048**	**E−01**
foot per second squared (ft / s^2)	meter per second squared (m / s^2)	**3.048**	**E−01**
foot poundal	joule (J)	4.214 011	E−02
foot pound-force (ft · lbf)	joule (J)	1.355 818	E+00
foot pound-force per hour (ft · lbf / h)	watt (W)	3.766 161	E−04
foot pound-force per minute (ft · lbf / min)	watt (W)	2.259 697	E−02
foot pound-force per second (ft · lbf / s)	watt (W)	1.355 818	E+00
foot to the fourth power (ft^4)[16]	meter to the fourth power (m^4)	8.630 975	E−03
franklin (Fr)	coulomb (C)	3.335 641	E−10

[16] This is a unit for the quantity second moment of area, which is sometimes called the "moment of section" or "area moment of inertia" of a plane section about a specified axis.

To convert from	to	Multiply by	
gal (Gal)	meter per second squared (m / s^2)	**1.0**	**E−02**
gallon [Canadian and U.K. (Imperial)] (gal)	cubic meter (m^3)	**4.546 09**	**E−03**
gallon [Canadian and U.K. (Imperial)] (gal)	liter (L)	**4.546 09**	**E+00**
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412	E−03
gallon (U.S.) (gal)	liter (L)	3.785 412	E+00
gallon (U.S.) per day (gal / d)	cubic meter per second (m^3 / s)	4.381 264	E−08
gallon (U.S.) per day (gal / d)	liter per second (L / s)	4.381 264	E−05
gallon (U.S.) per horsepower hour [gal / (hp · h)]	cubic meter per joule (m^3 / J)	1.410 089	E−09
gallon (U.S.) per horsepower hour [gal / (hp · h)]	liter per joule (L / J)	1.410 089	E−06
gallon (U.S.) per minute (gpm)(gal / min)	cubic meter per second (m^3 / s)	6.309 020	E−05
gallon (U.S.) per minute (gpm)(gal / min)	liter per second (L / s)	6.309 020	E−02
gamma (γ)	tesla (T)	**1.0**	**E−09**
gauss (Gs, G)	tesla (T)	**1.0**	**E−04**
gilbert (Gi)	ampere (A)	7.957 747	E−01
gill [Canadian and U.K. (Imperial)] (gi)	cubic meter (m^3)	1.420 653	E−04
gill [Canadian and U.K. (Imperial)] (gi)	liter (L)	1.420 653	E−01
gill (U.S.) (gi)	cubic meter (m^3)	1.182 941	E−04
gill (U.S.) (gi)	liter (L)	1.182 941	E−01
gon (also called grade) (gon)	radian (rad)	1.570 796	E−02
gon (also called grade) (gon)	degree (angle) (°)	**9.0**	**E−01**
grain (gr)	kilogram (kg)	**6.479 891**	**E−05**
grain (gr)	milligram (mg)	**6.479 891**	**E+01**
grain per gallon (U.S.) (gr / gal)	kilogram per cubic meter (kg / m^3)	1.711 806	E−02
grain per gallon (U.S.) (gr / gal)	milligram per liter (mg / L)	1.711 806	E+01
gram-force per square centimeter (gf / cm^2)	pascal (Pa)	**9.806 65**	**E+01**
gram per cubic centimeter (g / cm^3)	kilogram per cubic meter (kg / m^3)	**1.0**	**E+03**
hectare (ha)	square meter (m^2)	**1.0**	**E+04**
horsepower (550 ft · lbf / s) (hp)	watt (W)	7.456 999	E+02
horsepower (boiler)	watt (W)	9.809 50	E+03
horsepower (electric)	watt (W)	**7.46**	**E+02**
horsepower (metric)	watt (W)	7.354 988	E+02
horsepower (U.K.)	watt (W)	7.4570	E+02
horsepower (water)	watt (W)	7.460 43	E+02
hour (h)	second (s)	**3.6**	**E+03**
hour (sidereal)	second (s)	3.590 170	E+03
hundredweight (long, 112 lb)	kilogram (kg)	5.080 235	E+01
hundredweight (short, 100 lb)	kilogram (kg)	4.535 924	E+01
inch (in)	meter (m)	**2.54**	**E−02**
inch (in)	centimeter (cm)	**2.54**	**E+00**
inch of mercury (32 °F)[12]	pascal (Pa)	3.386 38	E+03
inch of mercury (32 °F)[12]	kilopascal (kPa)	3.386 38	E+00
inch of mercury (60 °F)[12]	pascal (Pa)	3.376 85	E+03
inch of mercury (60 °F)[12]	kilopascal (kPa)	3.376 85	E+00
inch of mercury, conventional (inHg)[12]	pascal (Pa)	3.386 389	E+03
inch of mercury, conventional (inHg)[12]	kilopascal (kPa)	3.386 389	E+00
inch of water (39.2 °F)[12]	pascal (Pa)	2.490 82	E+02
inch of water (60 °F)[12]	pascal (Pa)	2.4884	E+02
inch of water, conventional (inH_2O)[12]	pascal (Pa)	2.490 889	E+02
inch per second (in / s)	meter per second (m / s)	**2.54**	**E−02**

To convert from	to	Multiply by	
inch per second squared (in / s^2)	meter per second squared (m / s^2)	**2.54**	**E−02**
inch to the fourth power (in^4)[16]	meter to the fourth power (m^4)	4.162 314	E−07
kayser (K)	reciprocal meter (m^{-1})	**1.0**	**E+02**
kelvin (K)	degree Celsius (°C)	$t/°C = T/K - 273.15$	
kilocalorie$_{IT}$ (kcal$_{IT}$)	joule (J)	**4.1868**	**E+03**
kilocalorie$_{th}$ (kcal$_{th}$)	joule (J)	**4.184**	**E+03**
kilocalorie (mean) (kcal)	joule (J)	4.190 02	E+03
kilocalorie$_{th}$ per minute (kcal$_{th}$ / min)	watt (W	6.973 333	E+01
kilocalorie$_{th}$ per second (kcal$_{th}$ / s)	watt (W	**4.184**	**E+03**
kilogram-force (kgf)	newton (N)	**9.806 65**	**E+00**
kilogram-force meter (kgf · m)	newton meter (N · m)	**9.806 65**	**E+00**
kilogram-force per square centimeter (kgf / cm^2)	pascal (Pa)	**9.806 65**	**E+04**
kilogram-force per square centimeter (kgf / cm^2)	kilopascal (kPa)	**9.806 65**	**E+01**
kilogram-force per square meter (kgf / m^2)	pascal (Pa)	**9.806 65**	**E+00**
kilogram-force per square millimeter (kgf / mm^2)	pascal (Pa)	**9.806 65**	**E+06**
kilogram-force per square millimeter (kgf / mm^2)	megapascal (MPa)	**9.806 65**	**E+00**
kilogram-force second squared per meter (kgf · s^2 / m)	kilogram (kg)	**9.806 65**	**E+00**
kilometer per hour (km / h)	meter per second (m / s)	2.777 778	E−01
kilopond (kilogram-force) (kp)	newton (N)	**9.806 65**	**E+00**
kilowatt hour (kW · h)	joule (J)	**3.6**	**E+06**
kilowatt hour (kW · h)	megajoule (MJ)	**3.6**	**E+00**
kip (1 kip =1 000 lbf)	newton (N)	4.448 222	E+03
kip (1 kip = 1000 lbf)	kilonewton (kN)	4.448 222	E+00
kip per square inch (ksi) (kip / in^2)	pascal (Pa)	6.894 757	E+06
kip per square inch (ksi) (kip / in^2)	kilopascal (kPa)	6.894 757	E+03
knot (nautical mile per hour)	meter per second (m / s)	5.144 444	E−01
lambert[17]	candela per square meter (cd / m^2)	3.183 099	E+03
langley (calth / cm^2)	joule per square meter (J / m^2)	**4.184**	**E+04**
light year (l.y.)[18]	meter (m)	9.460 73	E+15
liter (L)[19]	cubic meter (m^3)	**1.0**	**E−03**
lumen per square foot (lm / ft^2)	lux (lx)	1.076 391	E+01
maxwell (Mx)	weber (Wb)	**1.0**	**E−08**
mho	siemens (S)	**1.0**	**E+00**
microinch	meter (m)	**2.54**	**E−08**
microinch	micrometer (μm)	**2.54**	**E−02**
micron (μ)	meter (m)	**1.0**	**E−06**
micron (μ)	micrometer (μm)	**1.0**	**E+00**
mil (0.001 in)	meter (m)	**2.54**	**E−05**
mil (0.001 in)	millimeter (mm)	**2.54**	**E−02**

[17] The exact conversion factor is $10^4/\pi$.
[18] This conversion factor is based on 1 d = 86 400 s; and 1 Julian century = 36 525 d. (See The Astronomical Almanac for the Year 1995, page K6, U.S. Government Printing Office, Washington, DC, 1994).
[19] In 1964 the General Conference on Weights and Measures reestablished the name "liter" as a special name for the cubic decimeter. Between 1901 and 1964 the liter was slightly larger (1.000 028 dm_3); when one uses high-accuracy volume data of that time, this fact must be kept in mind.

To convert from	to	Multiply by
mil (angle)	radian (rad)	9.817 477 E−04
mil (angle)	degree (°)	**5.625 E−02**
mile (mi)	meter (m)	**1.609 344 E+03**
mile (mi)	kilometer (km)	**1.609 344 E+00**
mile (based on U.S. survey foot) (mi)[7]	meter (m)	1.609 347 E+03
mile (based on U.S. survey foot) (mi)[7]	kilometer (km)	1.609 347 E+00
mile, nautical[20]	meter (m)	**1.852 E+03**
mile per gallon (U.S.) (mpg) (mi / gal)	meter per cubic meter (m / m^3)	4.251 437 E+05
mile per gallon (U.S.) (mpg) (mi / gal)	kilometer per liter (km / L)	4.251 437 E−01
mile per gallon (U.S.) (mpg) (mi / gal)[21]	liter per 100 kilometer (L / 100 km)	divide 235.215 by number of miles per gallon
mile per hour (mi / h)	meter per second (m / s)	**4.4704 E−01**
mile per hour (mi / h)	kilometer per hour (km / h)	**1.609 344 E+00**
mile per minute (mi / min)	meter per second (m / s)	**2.682 24 E+01**
mile per second (mi / s)	meter per second (m / s)	**1.609 344 E+03**
millibar (mbar)	pascal (Pa)	**1.0 E+02**
millibar (mbar)	kilopascal (kPa)	**1.0 E−01**
millimeter of mercury, conventional (mmHg)[12]	pascal (Pa)	1.333 224 E+02
millimeter of water, conventional (mmH_2O)[12]	pascal (Pa)	**9.806 65 E+00**
minute (angle) (')	radian (rad)	2.908 882 E−04
minute (min)	second (s)	**6.0 E+01**
minute (sidereal)	second (s)	5.983 617 E+01
oersted (Oe)	ampere per meter (A / m)	7.957 747 E+01
ohm centimeter (Ω · cm)	ohm meter (Ω·m)	**1.0 E−02**
ohm circular-mil per foot	ohm meter (Ω·m)	1.662 426 E−09
ohm circular-mil per foot	ohm square millimeter per meter (Ω·mm^2 / m)	1.662 426 E−03
ounce (avoirdupois) (oz)	kilogram (kg)	2.834 952 E−02
ounce (avoirdupois) (oz)	gram (g)	2.834 952 E+01
ounce (troy or apothecary) (oz)	kilogram (kg)	3.110 348 E−02
ounce (troy or apothecary) (oz)	gram (g)	3.110 348 E+01
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	cubic meter (m^3)	2.841 306 E−05
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	milliliter (mL)	2.841 306 E+01
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E−05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01
ounce (avoirdupois)-force (ozf)	newton (N)	2.780 139 E−01
ounce (avoirdupois)-force inch (ozf · in)	newton meter (N·m)	7.061 552 E−03
ounce (avoirdupois)-force inch (ozf · in)	millinewton meter (mN·m)	7.061 552 E+00
ounce (avoirdupois) per cubic inch (oz / in^3)	kilogram per cubic meter (kg / m^3)	1.729 994 E+03
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz / gal)	kilogram per cubic meter (kg / m^3)	6.236 023 E+00
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz / gal)	gram per liter (g / L)	6.236 023 E+00
ounce (avoirdupois) per gallon(U.S.)(oz / gal)	kilogram per cubic meter (kg / m^3)	7.489 152 E+00
ounce (avoirdupois) per gallon(U.S.)(oz / gal)	gram per liter (g / L)	7.489 152 E+00
ounce (avoirdupois) per square foot (oz / ft^2)	kilogram per square meter (kg / m^2)	3.051 517 E−01

[20] The value of this unit, 1 nautical mile = 1852 m, was adopted by the First International Extraordinary Hydrographic Conference, Monaco, 1929, under the name "International nautical mile."
[21] See Sec. B.5.

To convert from	to	Multiply by	
ounce (avoirdupois) per square inch (oz / in^2)	kilogram per square meter (kg / m^2)	4.394 185	E+01
ounce (avoirdupois) per square yard(oz / yd^2)	kilogram per square meter (kg / m^2)	3.390 575	E−02
parsec (pc)	meter (m)	3.085 678	E+16
peck (U.S.) (pk)	cubic meter (m^3)	8.809 768	E−03
peck (U.S.) (pk)	liter (L)	8.809 768	E+00
pennyweight (dwt)	kilogram (kg)	1.555 174	E−03
pennyweight (dwt)	gram (g)	1.555 174	E+00
perm (0 °C)	kilogram per pascal second square meter [kg / (Pa·s·m^2)]	5.721 35	E−11
perm (23 °C)	kilogram per pascal second square meter [kg / (Pa·s·m^2)]	5.745 25	E−11
perm inch (0 °C)	kilogram per pascal second meter [kg / (Pa·s·m)]	1.453 22	E−12
perm inch (23 °C)	kilogram per pascal second meter [kg / (Pa·s·m)]	1.459 29	E−12
phot (ph)	lux (lx)	**1.0**	**E+04**
pica (computer) (1/6 in)	meter (m)	4.233 333	E−03
pica (computer) (1/6 in)	millimeter (mm)	4.233 333	E+00
pica (printer's)	meter (m)	4.217 518	E−03
pica (printer's)	millimeter (mm)	4.217 518	E+00
pint (U.S. dry) (dry pt)	cubic meter (m^3)	5.506 105	E−04
pint (U.S. dry) (dry pt)	liter (L)	5.506 105	E−01
pint (U.S. liquid) (liq pt)	cubic meter (m^3)	4.731 765	E−04
pint (U.S. liquid) (liq pt)	liter (L)	4.731 765	E−01
point (computer) (1/72 in)	meter (m)	3.527 778	E−04
point (computer) (1/72 in)	millimeter (mm)	3.527 778	E−01
point (printer's)	meter (m)	3.514 598	E−04
point (printer's)	millimeter (mm)	3.514 598	E−01
poise (P)	pascal second (Pa·s)	**1.0**	**E−01**
pound (avoirdupois) (lb)[22]	kilogram (kg)	4.535 924	E−01
pound (troy or apothecary) (lb)	kilogram (kg)	3.732 417	E−01
poundal	newton (N)	1.382 550	E−01
poundal per square foot	pascal (Pa)	1.488 164	E+00
poundal second per square foot	pascal second (Pa·s)	1.488 164	E+00
pound foot squared (lb · ft^2)	kilogram meter squared (kg ·m^2)	4.214 011	E−02
pound-force (lbf)[23]	newton (N)	4.448 222	E+00
pound-force foot (lbf · ft)	newton meter (N · m)	1.355 818	E+00
pound-force foot per inch (lbf · ft / in)	newton meter per meter (N · m / m)	5.337 866	E+01
pound-force inch (lbf · in)	newton meter (N · m)	1.129 848	E−01
pound-force inch per inch (lbf · in / in)	newton meter per meter (N · m / m)	4.448 222	E+00
pound-force per foot (lbf / ft)	newton per meter (N / m)	1.459 390	E+01
pound-force per inch (lbf/ in)	newton per meter (N / m)	1.751 268	E+02
pound-force per pound (lbf/lb) (thrust to mass ratio)	newton per kilogram (N / kg)	**9.806 65**	**E+00**
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026	E+01
pound-force per square inch (psi) (lbf/in^2)	pascal (Pa)	6.894 757	E+03
pound-force per square inch (psi) (lbf/in^2)	kilopascal (kPa)	6.894 757	E+00

[22] The exact conversion factor is 4.535 923 7 E−01. All units in Secs. B.8 and B.9 that contain the pound refer to the avoirdupois pound.
[23] If the local value of the acceleration of free fall is taken as g_n=9.806 65 m/s^2 (the standard value), the exact conversion factor is 4.448 221 615 260 5 E+00.

To convert from	to	Multiply by	
pound-force second per square foot (lbf · s/ft^2)	pascal second (Pa · s)	4.788 026	E+01
pound-force second per square inch (lbf · s/in^2)	pascal second (Pa · s)	6.894 757	E+03
pound inch squared (lb · in^2)	kilogram meter squared (kg·m^2)	2.926 397	E−04
pound per cubic foot (lb / ft^3)	kilogram per cubic meter (kg / m^3)	1.601 846	E+01
pound per cubic inch (lb / in^3)	kilogram per cubic meter (kg / m^3)	2.767 990	E+04
pound per cubic yard (lb /yd^3)	kilogram per cubic meter (kg / m^3)	5.932 764	E−01
pound per foot (lb / ft)	kilogram per meter (kg / m)	1.488 164	E+00
pound per foot hour [lb/(ft · h)]	pascal second (Pa · s)	4.133 789	E−04
pound per foot second [lb / (ft · s)]	pascal second (Pa · s)	1.488 164	E+00
pound per gallon [Canadian and U.K. (Imperial)] (lb / gal)	kilogram per cubic meter (kg / m^3)	9.977 637	E+01
pound per gallon [Canadian and U.K. (Imperial)] (lb / gal)	kilogram per liter (kg / L)	9.977 637	E−02
pound per gallon (U.S.) (lb / gal)	kilogram per cubic meter (kg / m^3)	1.198 264	E+02
pound per gallon (U.S.) (lb / gal)	kilogram per liter (kg / L)	1.198 264	E−01
pound per horsepower hour [lb / (hp · h)]	kilogram per joule (kg / J)	1.689 659	E−07
pound per hour (lb / h)	kilogram per second (kg / s)	1.259 979	E−04
pound per inch (lb / in)	kilogram per meter (kg / m)	1.785 797	E+01
pound per minute (lb / min)	kilogram per second (kg / s)	7.559 873	E−03
pound per second (lb / s)	kilogram per second (kg / s)	4.535 924	E−01
pound per square foot (lb / ft^2)	kilogram per square meter (kg / m^2)	4.882 428	E+00
pound per square inch (*not* pound-force) (lb / in^2)	kilogram per square meter (kg / m^2)	7.030 696	E+02
pound per yard (lb / yd)	kilogram per meter (kg / m)	4.960 546	E−01
psi (pound-force per square inch) (lbf / in^2)	pascal (Pa)	6.894 757	E+03
psi (pound-force per square inch) (lbf / in^2)	kilopascal (kPa)	6.894 757	E+00
quad (10^{15} Btu_{IT})[11]	joule (J)	1.055 056	E+18
quart (U.S. dry) (dry qt)	cubic meter (m^3)	1.101 221	E−03
quart (U.S. dry) (dry qt)	liter (L)	1.101 221	E+00
quart (U.S. liquid) (liq qt)	cubic meter (m^3)	9.463 529	E−04
quart (U.S. liquid) (liq qt)	liter (L)	9.463 529	E−01
rad (absorbed dose) (rad)	gray (Gy)	**1.0**	**E−02**
rem (rem)	sievert (Sv)	**1.0**	**E−02**
revolution (r)	radian (rad)	6.283 185	E+00
revolution per minute (rpm) (r / min)	radian per second (rad / s)	1.047 198	E−01
rhe	reciprocal pascal second (Pa·s)$^{-1}$	**1.0**	**E+01**
rod (based on U.S. survey foot) (rd)[7]	meter (m)	5.029 210	E+00
roentgen (R)	coulomb per kilogram (C / kg)	**2.58**	**E−04**
rpm (revolution per minute) (r / min)	radian per second (rad / s)	1.047 198	E−01
second (angle) (")	radian (rad)	4.848 137	E−06
second (sidereal)	second (s)	9.972 696	E−01
shake	second (s)	**1.0**	**E−08**
shake	nanosecond (ns)	**1.0**	**E+01**
slug (slug)	kilogram (kg)	1.459 390	E+01
slug per cubic foot (slug / ft^3)	kilogram per cubic meter (kg / m^3)	5.153 788	E+02
slug per foot second [slug / (ft · s)]	pascal second (Pa·s)	4.788 026	E+01
square foot (ft^2)	square meter (m^2)	**9.290 304**	**E−02**
square foot per hour (ft^2 / h)	square meter per second (m^2 / s)	**2.580 64**	**E−05**

To convert from	to	Multiply by	
square foot per second (ft^2 / s)	square meter per second (m^2 / s)	**9.290 304**	**E−02**
square inch (in^2)	square meter (m^2)	**6.4516**	**E−04**
square inch (in^2)	square centimeter (cm^2)	**6.4516**	**E+00**
square mile (mi^2)	square meter (m^2)	2.589 988	E+06
square mile (mi^2)	square kilometer (km^2)	2.589 988	E+00
square mile (based on U.S. survey foot) (mi^2)[7]	square meter (m^2)	2.589 998	E+06
square mile (based on U.S. survey foot) (mi^2)[7]	square kilometer (km^2)	2.589 998	E+00
square yard (yd^2)	square meter (m^2)	8.361 274	E−01
statampere	ampere (A)	3.335 641	E−10
statcoulomb	coulomb (C)	3.335 641	E−10
statfarad	farad (F)	1.112 650	E−12
stathenry	henry (H)	8.987 552	E+11
statmho	siemens (S)	1.112 650	E−12
statohm	ohm (Ω)	8.987 552	E+11
statvolt	volt (V)	2.997 925	E+02
stere (st)	cubic meter (m^3)	**1.0**	**E+00**
stilb (sb)	candela per square meter (cd / m^2)	**1.0**	**E+04**
stokes (St)	meter squared per second (m^2 / s)	**1.0**	**E−04**
tablespoon	cubic meter (m^3)	1.478 676	E−05
tablespoon	milliliter (mL)	1.478 676	E+01
teaspoon	cubic meter (m^3)	4.928 922	E−06
teaspoon	milliliter (mL)	4.928 922	E+00
tex	kilogram per meter (kg / m)	**1.0**	**E−06**
therm (EC)[24]	joule (J)	**1.055 06**	**E+08**
therm (U.S.)[24]	joule (J)	**1.054 804**	**E+08**
ton, assay (AT)	kilogram (kg)	2.916 667	E−02
ton, assay (AT)	gram (g)	2.916 667	E+01
ton-force (2000 lbf)	newton (N)	8.896 443	E+03
ton-force (2000 lbf)	kilonewton (kN)	8.896 443	E+00
ton, long (2240 lb)	kilogram (kg)	1.016 047	E+03
ton, long, per cubic yard	kilogram per cubic meter (kg / m^3)	1.328 939	E+03
ton, metric (t)	kilogram (kg)	**1.0**	**E+03**
tonne (called “metric ton” in U.S.) (t)	kilogram (kg)	**1.0**	**E+03**
ton of refrigeration (12 000 Btu_{IT} / h)	watt (W)	3.516 853	E+03
ton of TNT (energy equivalent)[25]	joule (J)	**4.184**	**E+09**
ton, register	cubic meter (m^3)	2.831 685	E+00
ton, short (2000 lb)	kilogram (kg)	9.071 847	E+02
ton, short, per cubic yard	kilogram per cubic meter (kg / m^3)	1.186 553	E+03
ton, short, per hour	kilogram per second (kg / s)	2.519 958	E−01
torr (Torr)	pascal (Pa)	1.333 224	E+02
unit pole	weber (Wb)	1.256 637	E−07
watt hour (W · h)	joule (J)	**3.6**	**E+03**
watt per square centimeter (W / cm^2)	watt per square meter (W / m^2)	**1.0**	**E+04**

[24] The therm (EC) is legally defined in the Council Directive of 20 December 1979, Council of the European Communities (now the European Union, EU). The therm (U.S.) is legally defined in the *Federal Register* of July 27, 1968. Although the therm (EC), which is based on the International Table Btu, is frequently used by engineers in the United States, the therm (U.S.) is the legal unit used by the U.S. natural gas industry.

[25] Defined (not measured) value.

To convert from	to	Multiply by	
watt per square inch (W / in^2)	watt per square meter (W / m^2)	1.550 003	E+03
watt second (W · s)	joule (J)	**1.0**	**E+00**
yard (yd)	meter (m)	**9.144**	**E−01**
year (365 days)	second (s)	**3.1536**	**E+07**
year (sidereal)	second (s)	3.155 815	E+07
year (tropical)	second (s)	3.155 693	E+07

B.9 Factors for units listed by kind of quantity or field of science

Caution: The units listed in column 1 are in general not to be used in NIST publications, with the exception of those few in italic type.

Factors in **boldface** are exact

To convert from	to	Multiply by	
ACCELERATION			
acceleration of free fall, standard (g_n)	meter per second squared (m / s^2)	**9.806 65**	**E+00**
foot per second squared (ft / s^2)	meter per second squared (m / s^2)	**3.048**	**E−01**
gal (Gal)	meter per second squared (m / s^2)	**1.0**	**E−02**
inch per second squared (in / s^2)	meter per second squared (m / s^2)	**2.54**	**E−02**
ANGLE			
degree (°)	radian (rad)	1.745 329	E−02
gon (also called grade) (gon)	radian (rad)	1.570 796	E−02
gon (also called grade) (gon)	degree (°)	**9.0**	**E−01**
mil	radian (rad)	9.817 477	E−04
mil	degree (°)	**5.625**	**E−02**
minute (')	radian (rad)	2.908 882	E−04
revolution (r)	radian (rad)	6.283 185	E+00
second ('')	radian (rad)	4.848 137	E−06
AREA AND SECOND MOMENT OF AREA			
acre (based on U.S. survey foot)	square meter (m^2)	4.046 873	E+03
are (a)	square meter (m^2)	**1.0**	**E+02**
barn (b)	square meter (m^2)	**1.0**	**E−28**
circular mil	square meter (m^2)	5.067 075	E−10
circular mil	square millimeter (mm^2)	5.067 075	E−04
foot to the fourth power (ft^4)[16]	meter to the fourth power (m^4)	8.630 975	E−03
hectare (ha)	square meter (m^2)	**1.0**	**E+04**
inch to the fourth power (in^4)[16]	meter to the fourth power (m^4)	4.162 314	E−07
square foot (ft^2)	square meter (m^2)	**9.290 304**	**E−02**
square inch (in^2)	square meter (m^2)	**6.4516**	**E−04**
square inch (in^2)	square centimeter (cm^2)	**6.4516**	**E+00**
square mile (mi^2)	square meter (m^2)	2.589 988	E+06
square mile (mi^2)	square kilometer (km^2)	2.589 988	E+00
square mile (based on U.S. survey foot) (mi^2)[7]	square meter (m^2)	2.589 998	E+06
square mile (based on U.S. survey foot) (mi^2)[7]	square kilometer (km^2)	2.589 998	E+00
square yard (yd^2)	square meter (m^2)	8.361 274	E−01
CAPACITY (see VOLUME)			
DENSITY (that is, MASS DENSITY— see MASS DIVIDED BY VOLUME)			
ELECTRICITY and MAGNETISM			
abampere	ampere (A)	**1.0**	**E+01**
abcoulomb	coulomb (C)	**1.0**	**E+01**
abfarad	farad (F)	**1.0**	**E+09**
abhenry	henry (H)	**1.0**	**E−09**
abmho	siemens (S)	**1.0**	**E+09**

To convert from	to	Multiply by	
abohm	ohm (Ω)	**1.0**	**E−09**
abvolt volt (V)	volt (V)	**1.0**	**E−08**
ampere hour (A · h)	coulomb (C)	**3.6**	**E+03**
biot (Bi)	ampere (A)	**1.0**	**E+01**
EMU of capacitance (abfarad)	farad (F)	**1.0**	**E+09**
EMU of current (abampere)	ampere (A)	**1.0**	**E+01**
EMU of electric potential (abvolt)	volt (V)	**1.0**	**E−08**
EMU of inductance (abhenry)	henry (H	**1.0**	**E−09**
EMU of resistance (abohm)	ohm (Ω)	**1.0**	**E−09**
ESU of capacitance (statfarad)	farad (F)	1.112 650	E−12
ESU of current (statampere)	ampere (A)	3.335 641	E−10
ESU of electric potential (statvolt)	volt (V)	2.997 925	E+02
ESU of inductance (stathenry)	henry (H)	8.987 552	E+11
ESU of resistance (statohm)	ohm (Ω)	8.987 552	E+11
faraday (based on carbon 12)	coulomb (C)	9.648 534	E+04
franklin (Fr)	coulomb (C)	3.335 641	E−10
gamma (γ)	tesla (T)	**1.0**	**E−09**
gauss (Gs, G)	tesla (T)	**1.0**	**E−04**
gilbert (Gi)	ampere (A)	7.957 747	E−01
maxwell (Mx)	weber (Wb)	**1.0**	**E−08**
mho	siemens (S)	**1.0**	**E+00**
oersted (Oe)	ampere per meter (A / m)	7.957 747	E+01
ohm centimeter (Ω · cm)	ohm meter (Ω · m)	**1.0**	**E−02**
ohm circular-mil per foot	ohm meter (Ω · m)	1.662 426	E−09
ohm circular-mil per foot	ohm square millimeter per meter (Ω · mm^2 / m)	1.662 426	E−03
statampere	ampere (A)	3.335 641	E−10
statcoulomb	coulomb (C)	3.335 641	E−10
statfarad	farad (F)	1.112 650	E−12
stathenry	henry (H)	8.987 552	E+11
statmho	siemens (S)	1.112 650	E−12
statohm	ohm (Ω)	8.987 552	E+11
statvolt	volt (V)	2.997 925	E+02
unit pole	weber (Wb)	1.256 637	E−07

ENERGY (includes WORK)

British thermal unit$_{IT}$ (Btu$_{IT}$)[9]	joule (J)	1.055 056	E+03
British thermal unit$_{th}$ (Btu$_{th}$)[9]	joule (J)	1.054 350	E+03
British thermal unit (mean) (Btu)	joule (J)	1.055 87	E+03
British thermal unit (39 °F) (Btu)	joule (J)	1.059 67	E+03
British thermal unit (59 °F) (Btu)	joule (J)	1.054 80	E+03
British thermal unit (60 °F) (Btu)	joule (J)	1.054 68	E+03
calorie$_{IT}$ (cal$_{IT}$)[10]	joule (J)	**4.1868**	**E+00**
calorie$_{th}$ (cal$_{th}$)[10]	joule (J)	**4.184**	**E+00**
calorie (mean) (cal)	joule (J)	4.190 02	E+00
calorie (15 °C) (cal$_{15}$)	joule (J)	4.185 80	E+00
calorie (20 °C) (cal$_{20}$)	joule (J)	4.181 90	E+00
calorie$_{IT}$, kilogram (nutrition)[11]	joule (J)	**4.1868**	**E+03**
calorie$_{th}$, kilogram (nutrition)[11]	joule (J)	**4.184**	**E+03**
calorie (mean), kilogram (nutrition)[11]	joule (J)	4.190 02	E+03
electronvolt (eV)	joule (J)	1.602 176	E−19
erg (erg)	joule (J)	**1.0**	**E−07**
foot poundal	joule (J)	4.214 011	E−02

To convert from	to	Multiply by	
foot pound-force (ft · lbf)	joule (J)	1.355 818	E+00
kilocalorie$_{IT}$ (kcal$_{IT}$)	joule (J)	**4.1868**	**E+03**
kilocalorie$_{th}$ (kcal$_{th}$)	joule (J)	**4.184**	**E+03**
kilocalorie (mean) (kcal)	joule (J)	4.190 02	E+03
kilowatt hour (kW · h)	joule (J)	**3.6**	**E+06**
kilowatt hour (kW · h)	megajoule (MJ)	**3.6**	**E+00**
quad (1015 Btu$_{IT}$)[9]	joule (J)	1.055 056	E+18
therm (EC)[24]	joule (J)	**1.055 06**	**E+08**
therm (U.S.)[24]	joule (J)	**1.054 804**	**E+08**
ton of TNT (energy equivalent)[25]	joule (J)	**4.184**	**E+09**
watt hour (W · h)	joule (J)	**3.6**	**E+03**
watt second (W · s)	joule (J)	**1.0**	**E+00**

ENERGY DIVIDED BY AREA TIME

erg per square centimeter second [erg / (cm^2 · s)]	watt per square meter (W / m^2)	**1.0**	**E−03**
watt per square centimeter (W / cm^2)	watt per square meter (W / m^2)	**1.0**	**E+04**
watt per square inch (W / in^2)	watt per square meter (W / m^2)	1.550 003	E+03

FLOW (see MASS DIVIDED BY TIME or VOLUME DIVIDED BY TIME)

FORCE

dyne (dyn)	newton (N)	**1.0**	**E−05**
kilogram-force (kgf)	newton (N)	**9.806 65**	**E+00**
kilopond (kilogram-force) (kp)	newton (N)	**9.806 65**	**E+00**
kip (1 kip = 1000 lbf)	newton (N)	4.448 222	E+03
kip (1 kip = 1000 lbf)	kilonewton (kN)	4.448 222	E+00
ounce (avoirdupois)-force (ozf)	newton (N)	2.780 139	E−01
poundal	newton (N)	1.382 550	E−01
pound-force (lbf)[23]	newton (N)	4.448 222	E+00
pound-force per pound (lbf / lb) (thrust to mass ratio)	newton per kilogram (N / kg)	**9.806 65**	**E+00**
ton-force (2000 lbf)	newton (N)	8.896 443	E+03
ton-force (2000 lbf)	kilonewton (kN)	8.896 443	E+00

FORCE DIVIDED BY AREA (see PRESSURE)

FORCE DIVIDED BY LENGTH

pound-force per foot (lbf / ft)	newton per meter (N / m)	1.459 390	E+01
pound-force per inch (lbf / in)	newton per meter (N / m)	1.751 268	E+02

HEAT

Available Energy

British thermal unit$_{IT}$ per cubic foot (Btu$_{IT}$ / ft^3)	joule per cubic meter (J / m^3)	3.725 895	E+04
British thermal unit$_{th}$ per cubic foot (Btu$_{th}$ / ft^3)	joule per cubic meter (J / m^3)	3.723 403	E+04
British thermal unit$_{IT}$ per pound (Btu$_{IT}$ / lb)	joule per kilogram (J / kg)	**2.326**	**E+03**
British thermal unit$_{th}$ per pound (Btu$_{th}$ / lb)	joule per kilogram (J / kg)	2.324 444	E+03
calorie$_{IT}$ per gram (cal$_{IT}$ / g)	joule per kilogram (J / kg)	**4.1868**	**E+03**
calorie$_{th}$ per gram (cal$_{th}$ / g)	joule per kilogram (J / kg)	**4.184**	**E+03**

To convert from	to	Multiply by
Coefficient of Heat Transfer		
British thermal unit_{IT} per hour square foot degree Fahrenheit $[\text{Btu}_{IT} / (\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})]$	watt per square meter kelvin $[\text{W} / (\text{m}^2 \cdot \text{K})]$	5.678 263 E+00
British thermal unit_{th} per hour square foot degree Fahrenheit $[\text{Btu}_{th} / (\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})]$	watt per square meter kelvin $[\text{W} / (\text{m}^2 \cdot \text{K})]$	5.674 466 E+00
British thermal unit_{IT} per second square foot degree Fahrenheit $[\text{Btu}_{IT} / (\text{s} \cdot \text{ft}^2 \cdot {}^\circ\text{F})]$	watt per square meter kelvin $[\text{W} / (\text{m}^2 \cdot \text{K})]$	2.044 175 E+04
British thermal unit_{th} per second square foot degree Fahrenheit $[\text{Btu}_{th} / (\text{s} \cdot \text{ft}^2 \cdot {}^\circ\text{F})]$	watt per square meter kelvin $[\text{W} / (\text{m}^2 \cdot \text{K})]$	2.042 808 E+04
Density of Heat		
British thermal unit_{IT} per square foot $(\text{Btu}_{IT} / \text{ft}^2)$	joule per square meter (J / m^2)	1.135 653 E+04
British thermal unit_{th} per square foot $(\text{Btu}_{th} / \text{ft}^2)$	joule per square meter (J / m^2)	1.134 893 E+04
calorie_{th} per square centimeter $(\text{cal}_{th} / \text{cm}^2)$	joule per square meter (J / m^2)	**4.184 E+04**
langley $(\text{cal}_{th} / \text{cm}^2)$	joule per square meter (J / m^2)	**4.184 E+04**
Density of Heat Flow Rate		
British thermal unit_{IT} per square foot hour $[\text{Btu}_{IT} / (\text{ft}^2 \cdot \text{h})]$	watt per square meter (W / m^2)	3.154 591 E+00
British thermal unit_{th} per square foot hour $[\text{Btu}_{th} / (\text{ft}^2 \cdot \text{h})]$	watt per square meter (W / m^2)	3.152 481 E+00
British thermal unit_{th} per square foot minute $[\text{Btu}_{th} / (\text{ft}^2 \cdot \text{min})]$	watt per square meter (W / m^2)	1.891 489 E+02
British thermal unit_{IT} per square foot second $[\text{Btu}_{IT} / (\text{ft}^2 \cdot \text{s})]$	watt per square meter (W / m^2)	1.135 653 E+04
British thermal unit_{th} per square foot second $[\text{Btu}_{th} / (\text{ft}^2 \cdot \text{s})]$	watt per square meter (W / m^2)	1.134 893 E+04
British thermal unit_{th} per square inch second $[\text{Btu}_{th} / (\text{in}^2 \cdot \text{s})]$	watt per square meter (W / m^2)	1.634 246 E+06
calorie_{th} per square centimeter minute $[\text{cal}_{th} / (\text{cm}^2 \cdot \text{min})]$	watt per square meter (W / m^2)	6.973 333 E+02
calorie_{th} per square centimeter second $[\text{cal}_{th} / (\text{cm}^2 \cdot \text{s})]$	watt per square meter (W / m^2)	**4.184 E+04**
Fuel Consumption		
gallon (U.S.) per horsepower hour $[\text{gal} / (\text{hp} \cdot \text{h})]$	cubic meter per joule (m^3 / J)	1.410 089 E−09
gallon (U.S.) per horsepower hour $[\text{gal} / (\text{hp} \cdot \text{h})]$	liter per joule (L / J)	1.410 089 E−06
mile per gallon (U.S.) (mpg) (mi / gal)	meter per cubic meter (m / m^3)	4.251 437 E+05
mile per gallon (U.S.) (mpg) (mi / gal)	kilometer per liter (km / L)	4.251 437 E−01
mile per gallon (U.S.) (mpg) (mi / gal)[21]	liter per 100 kilometer (L / 100 km)	divide 235.215 by number of miles per gallon
pound per horsepower hour $[\text{lb} / (\text{hp} \cdot \text{h})]$	kilogram per joule (kg / J)	1.689 659 E−07

To convert from	to	Multiply by	
Heat Capacity and Entropy			
British thermal unit$_{IT}$ per degree Fahrenheit (Btu$_{IT}$ / °F)	joule per kelvin (J / k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Fahrenheit (Btu$_{th}$ / °F)	joule per kelvin (J / k)	1.897 830	E+03
British thermal unit$_{IT}$ per degree Rankine (Btu$_{IT}$ / °R)	joule per kelvin (J / k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Rankine (Btu$_{th}$ / °R)	joule per kelvin (J / k)	1.897 830	E+03
Heat Flow Rate			
British thermal unit$_{IT}$ per hour (Btu$_{IT}$ / h)	watt (W)	2.930 711	E−01
British thermal unit$_{th}$ per hour (Btu$_{th}$ / h)	watt (W)	2.928 751	E−01
British thermal unit$_{th}$ per minute (Btu$_{th}$ / min)	watt (W)	1.757 250	E+01
British thermal unit$_{IT}$ per second (Btu$_{IT}$ / s)	watt (W)	1.055 056	E+03
British thermal unit$_{th}$ per second (Btu$_{th}$ / s)	watt (W)	1.054 350	E+03
calorie$_{th}$ per minute (cal$_{th}$ / min)	watt (W)	6.973 333	E−02
calorie$_{th}$ per second (cal$_{th}$ / s)	watt (W)	**4.184**	**E+00**
kilocalorie$_{th}$ per minute (kcal$_{th}$ / min)	watt (W)	6.973 333	E+01
kilocalorie$_{th}$ per second (kcal$_{th}$ / s)	watt (W)	**4.184**	**E+03**
ton of refrigeration (12 000 Btu$_{IT}$ / h)	watt (W)	3.516 853	E+03
Specific Heat Capacity and Specific Entropy			
British thermal unit$_{IT}$ per pound degree Fahrenheit [Btu$_{IT}$ / (lb · °F)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Fahrenheit [Btu$_{th}$ / (lb · °F)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
British thermal unit$_{IT}$ per pound degree Rankine [Btu$_{IT}$ / (lb · °R)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Rankine [Btu$_{th}$ / (lb · °R)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
calorie$_{IT}$ per gram degree Celsius [cal$_{IT}$ / (g · °C)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram degree Celsius [cal$_{th}$ / (g · °C)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
calorie$_{IT}$ per gram kelvin [cal$_{IT}$ / (g · K)]	joule per kilogram kelvin [J / (kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram kelvin [cal$_{th}$ / (g · K)]	joule per kilogram kelvin [J / (kg · K)]	**4.184**	**E+03**
Thermal Conductivity			
British thermal unit$_{IT}$ foot per hour square foot degree Fahrenheit [Btu$_{IT}$ · ft / (h · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	1.730 735	E+00
British thermal unit$_{th}$ foot per hour square foot degree Fahrenheit [Btu$_{th}$. ft / (h · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	1.729 577	E+00
British thermal unit$_{IT}$ inch per hour square foot degree Fahrenheit [Btu$_{IT}$ · in / (h · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	1.442 279	E−01
British thermal unit$_{th}$ inch per hour square foot degree Fahrenheit [Btu$_{th}$ · in / (h · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	1.441 314	E−01
British thermal unit$_{IT}$ inch per second square foot degree Fahrenheit [Btu$_{IT}$ · in / (s · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	5.192 204	E+02
British thermal unit$_{th}$ inch per second square foot degree Fahrenheit [Btu$_{th}$ · in / (s · ft^2 · °F)]	watt per meter kelvin [W / (m · K)]	5.188 732	E+02
calorie$_{th}$ per centimeter second degree Celsius [cal$_{th}$ / (cm · s · °C)]	watt per meter kelvin [W / (m·K)]	**4.184**	**E+02**

To convert from	to	Multiply by	
Thermal Diffusivity			
square foot per hour (ft^2 / h)	square meter per second (m^2 / s)	**2.580 64**	**E−05**
Thermal Insulance			
clo	square meter kelvin per watt ($m^2 \cdot K / W$)	1.55	E−01
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ ($°F \cdot h \cdot ft^2 / Btu_{IT}$)	square meter kelvin per watt ($m^2 \cdot K / W$)	1.761 102	E−01
degree Fahrenheit hour square foot per British thermal unit$_{th}$ ($°F \cdot h \cdot ft^2 / Btu_{th}$)	square meter kelvin per watt ($m^2 \cdot K / W$)	1.762 280	E−01
Thermal Resistance			
degree Fahrenheit hour per British thermal unit$_{IT}$ ($°F \cdot h / Btu_{IT}$)	kelvin per watt (K / W)	1.895 634	E+00
degree Fahrenheit hour per British thermal unit$_{th}$ ($°F \cdot h / Btu_{th}$)	kelvin per watt (K / W)	1.896 903	E+00
degree Fahrenheit second per British thermal unit$_{IT}$ ($°F \cdot s / Btu_{IT}$)	kelvin per watt (K / W)	5.265 651	E−04
degree Fahrenheit second per British thermal unit$_{th}$ ($°F \cdot s / Btu_{th}$)	kelvin per watt (K / W)	5.269 175	E−04
Thermal Resistivity			
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ inch [$°F \cdot h \cdot ft^2 / (Btu_{IT} \cdot in)$]	meter kelvin per watt ($m \cdot K / W$)	6.933 472	E+00
degree Fahrenheit hour square foot per British thermal unit$_{th}$ inch [$°F \cdot h \cdot ft^2 / (Btu_{th} \cdot in)$]	meter kelvin per watt ($m \cdot K / W$)	6.938 112	E+04
LENGTH			
ångström (Å)	meter (m)	**1.0**	**E−10**
ångström (Å)	nanometer (nm)	**1.0**	**E−01**
astronomical unit (ua)	meter (m)	1.495 979	E+11
chain (based on U.S. survey foot) (ch)[7]	meter (m)	2.011 684	E+01
fathom (based on U.S. survey foot)[7]	meter (m)	1.828 804	E+00
fermi	meter (m)	**1.0**	**E−15**
fermi	femtometer (fm)	**1.0**	**E+00**
foot (ft)	meter (m)	**3.048**	**E−01**
foot (U.S. survey) (ft)[7]	meter (m)	3.048 006	E−01
inch (in)	meter (m)	**2.54**	**E−02**
inch (in)	centimeter (cm)	**2.54**	**E+00**
kayser (K)	reciprocal meter (m^{-1})	**1**	**E+02**
light year (l.y.)[18]	meter (m)	9.460 73	E+15
microinch	meter (m)	**2.54**	**E−08**
microinch	micrometer (μm)	**2.54**	**E−02**
micron (μ)	meter (m)	**1.0**	**E−06**
micron (μ)	micrometer (μm)	**1.0**	**E+00**
mil (0.001 in)	meter (m)	**2.54**	**E−05**
mil (0.001 in)	millimeter (mm)	**2.54**	**E−02**
mile (mi)	meter (m)	**1.609 344**	**E+03**
mile (mi)	kilometer (km)	**1.609 344**	**E+00**
mile (based on U.S. survey foot) (mi)[7]	meter (m)	1.609 347	E+03
mile (based on U.S. survey foot) (mi)[7]	kilometer (km)	1.609 347	E+00

To convert from	to	Multiply by	
mile, nautical[20]	meter (m)	**1.852**	**E+03**
parsec (pc)	meter (m)	3.085 678	E+16
pica (computer) (1/6 in)	meter (m)	4.233 333	E−03
pica (computer) (1/6 in)	millimeter (mm)	4.233 333	E+00
pica (printer's)	meter (m)	4.217 518	E−03
pica (printer's)	millimeter (mm)	4.217 518	E+00
point (computer) (1/72 in)	meter (m)	3.527 778	E−04
point (computer) (1/72 in)	millimeter (mm)	3.527 778	E−01
point (printer's)	meter (m)	3.514 598	E−04
point (printer's)	millimeter (mm)	3.514 598	E−01
rod (based on U.S. survey foot) (rd)[7]	meter (m)	5.029 210	E+00
yard (yd)	meter (m)	**9.144**	**E−01**
LIGHT			
candela per square inch (cd / in^2)	candela per square meter (cd / m^2)	1.550 003	E+03
footcandle	lux (lx)	1.076 391	E+01
footlambert	candela per square meter (cd / m^2)	3.426 259	E+00
lambert[17]	candela per square meter (cd / m^2)	3.183 099	E+03
lumen per square foot (lm / ft^2)	lux (lx)	1.076 391	E+01
phot (ph)	lux (lx)	**1.0**	**E+04**
stilb (sb)	candela per square meter (cd / m^2)	**1.0**	**E+04**
MASS and MOMENT OF INERTIA			
carat, metric	kilogram (kg)	**2.0**	**E−04**
carat, metric	gram (g)	**2.0**	**E−01**
grain (gr)	kilogram (kg)	**6.479 891**	**E−05**
grain (gr)	milligram (mg)	**6.479 891**	**E+01**
hundredweight (long, 112 lb)	kilogram (kg)	5.080 235	E+01
hundredweight (short, 100 lb)	kilogram (kg)	4.535 924	E+01
kilogram-force second squared per meter ($kgf \cdot s^2 / m$)	kilogram (kg)	**9.806 65**	**E+00**
ounce (avoirdupois) (oz)	kilogram (kg)	2.834 952	E−02
ounce (avoirdupois) (oz)	gram (g)	2.834 952	E+01
ounce (troy or apothecary) (oz)	kilogram (kg)	3.110 348	E−02
ounce (troy or apothecary) (oz)	gram (g)	3.110 348	E+01
pennyweight (dwt)	kilogram (kg)	1.555 174	E−03
pennyweight (dwt)	gram (g)	1.555 174	E+00
pound (avoirdupois) (lb)[22]	kilogram (kg)	4.535 924	E−01
pound (troy or apothecary) (lb)	kilogram (kg)	3.732 417	E−01
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011	E−02
pound inch squared ($lb \cdot in^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397	E−04
slug (slug)	kilogram (kg)	1.459 390	E+01
ton, assay (AT)	kilogram (kg)	2.916 667	E−02
ton, assay (AT)	gram (g)	2.916 667	E+01
ton, long (2240 lb)	kilogram (kg)	1.016 047	E+03
ton, metric (t)	kilogram (kg)	**1.0**	**E+03**
tonne (called "metric ton" in U.S.) (t)	kilogram (kg)	**1.0**	**E+03**
ton, short (2000 lb)	kilogram (kg)	9.071 847	E+02

To convert from	to	Multiply by	
MASS DENSITY (see MASS DIVIDED BY VOLUME)			
MASS DIVIDED BY AREA			
ounce (avoirdupois) per square foot (oz / ft^2)	kilogram per square meter (kg / m^2)	3.051 517	E−01
ounce (avoirdupois) per square inch (oz / in^2)	kilogram per square meter (kg / m^2)	4.394 185	E+01
ounce (avoirdupois) per square yard (oz / yd^2)	kilogram per square meter (kg / m^2)	3.390 575	E−02
pound per square foot (lb / ft^2)	kilogram per square meter (kg / m^2)	4.882 428	E+00
pound per square inch (*not* pound force) (lb / in^2)	kilogram per square meter (kg / m^2)	7.030 696	E+02
MASS DIVIDED BY CAPACITY (see MASS DIVIDED BY VOLUME)			
MASS DIVIDED BY LENGTH			
denier	kilogram per meter (kg / m)	1.111 111	E−07
denier	gram per meter (g / m)	1.111 111	E−04
pound per foot (lb / ft)	kilogram per meter (kg / m)	1.488 164	E+00
pound per inch (lb / in)	kilogram per meter (kg / m)	1.785 797	E+01
pound per yard (lb / yd)	kilogram per meter (kg / m)	4.960 546	E−01
tex	kilogram per meter (kg / m)	**1.0**	**E−06**
MASS DIVIDED BY TIME (includes FLOW)			
pound per hour (lb / h)	kilogram per second (kg / s)	1.259 979	E−04
pound per minute (lb / min)	kilogram per second (kg / s)	7.559 873	E−03
pound per second (lb / s)	kilogram per second (kg / s)	4.535 924	E−01
ton, short, per hour	kilogram per second (kg / s)	2.519 958	E−01
MASS DIVIDED BY VOLUME (includes MASS DENSITY and MASS CONCENTRATION)			
grain per gallon (U.S.) (gr / gal)	kilogram per cubic meter (kg / m^3)	1.711 806	E−02
grain per gallon (U.S.) (gr / gal)	milligram per liter (mg / L)	1.711 806	E+01
gram per cubic centimeter (g / cm^3)	kilogram per cubic meter (kg / m^3)	**1.0**	**E+03**
ounce (avoirdupois) per cubic inch (oz / in^3)	kilogram per cubic meter (kg / m^3)	1.729 994	E+03
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz / gal)	kilogram per cubic meter (kg / m^3)	6.236 023	E+00
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz / gal)	gram per liter (g / L)	6.236 023	E+00
ounce (avoirdupois) per gallon (U.S.) (oz / gal)	kilogram per cubic meter (kg / m^3)	7.489 152	E+00
ounce (avoirdupois) per gallon (U.S.) (oz / gal)	gram per liter (g / L)	7.489 152	E+00
pound per cubic foot (lb / ft^3)	kilogram per cubic meter (kg / m^3)	1.601 846	E+01
pound per cubic inch (lb / in^3)	kilogram per cubic meter (kg / m^3)	2.767 990	E+04
pound per cubic yard (lb / yd^3)	kilogram per cubic meter (kg / m^3)	5.932 764	E−01
pound per gallon [Canadian and U.K. (Imperial)] (lb / gal)	kilogram per cubic meter (kg / m^3)	9.977 637	E+01
pound per gallon [Canadian and U.K. (Imperial)] (lb / gal)	kilogram per liter (kg / L)	9.977 637	E−02
pound per gallon (U.S.) (lb / gal)	kilogram per cubic meter (kg / m^3)	1.198 264	E+02
pound per gallon (U.S.) (lb / gal)	kilogram per liter (kg / L)	1.198 264	E−01
slug per cubic foot (slug / ft^3)	kilogram per cubic meter (kg / m^3)	5.153 788	E+02
ton, long, per cubic yard	kilogram per cubic meter (kg / m^3)	1.328 939	E+03
ton, short, per cubic yard	kilogram per cubic meter (kg / m^3)	1.186 553	E+03
MOMENT OF FORCE or TORQUE			
dyne centimeter (dyn · cm)	newton meter (N · m)	**1.0**	**E−07**

To convert from	to	Multiply by	
kilogram-force meter (kgf · m)	newton meter (N · m)	**9.806 65**	**E+00**
ounce (avoirdupois)-force inch (ozf · in)	newton meter (N·m)	7.061 552	E−03
ounce (avoirdupois)-force inch (ozf · in)	millinewton meter (mN · m)	7.061 552	E+00
pound-force foot (lbf · ft)	newton meter (N · m)	1.355 818	E+00
pound-force inch (lbf · in)	newton meter (N · m)	1.129 848	E−01

MOMENT OF FORCE or TORQUE, DIVIDED BY LENGTH

To convert from	to	Multiply by	
pound-force foot per inch (lbf · ft / in)	newton meter per meter (N · m / m)	5.337 866	E+01
pound-force inch per inch (lbf · in / in)	newton meter per meter (N · m / m)	4.448 222	E+00

PERMEABILITY

To convert from	to	Multiply by	
darcy[14]	meter squared (m^2)	9.869 233	E−13
perm (0 °C)	kilogram per pascal second square meter [kg / (Pa · s · m^2)]	5.721 35	E−11
perm (23 °C)	kilogram per pascal second square meter [kg / (Pa · s · m^2)]	5.745 25	E−11
perm inch (0 °C)	kilogram per pascal second meter [kg / (Pa · s · m)]	1.453 22	E−12
perm inch (23 °C)	kilogram per pascal second meter [kg / (Pa · s · m)]	1.459 29	E−12

POWER

To convert from	to	Multiply by	
erg per second (erg / s)	watt (W)	**1.0**	**E−07**
foot pound-force per hour (ft · lbf / h)	watt (W)	3.766 161	E−04
foot pound-force per minute (ft · lbf / min)	watt (W)	2.259 697	E−02
foot pound-force per second (ft · lbf / s)	watt (W)	1.355 818	E+00
horsepower (550 ft · lbf / s)	watt (W)	7.456 999	E+02
horsepower (boiler)	watt (W)	9.809 50	E+03
horsepower (electric)	watt (W)	**7.46**	**E+02**
horsepower (metric)	watt (W)	7.354 988	E+02
horsepower (U.K.)	watt (W)	7.4570	E+02
horsepower (water)	watt (W)	7.460 43	E+02

PRESSURE or STRESS (FORCE DIVIDED BY AREA)

To convert from	to	Multiply by	
atmosphere, standard (atm)	pascal (Pa)	**1.013 25**	**E+05**
atmosphere, standard (atm)	kilopascal (kPa)	**1.013 25**	**E+02**
atmosphere, technical (at)[8]	pascal (Pa)	**9.806 65**	**E+04**
atmosphere, technical (at)[8]	kilopascal (kPa)	**9.806 65**	**E+01**
bar (bar)	pascal (Pa)	**1.0**	**E+05**
bar (bar)	kilopascal (kPa)	**1.0**	**E+02**
centimeter of mercury (0 °C)[12]	pascal (Pa)	1.333 22	E+03
centimeter of mercury (0 °C)[12]	kilopascal (kPa)	1.333 22	E+00
centimeter of mercury, conventional (cmHg)[12]	pascal (Pa)	1.333 224	E+03
centimeter of mercury, conventional (cmHg)[12]	kilopascal (kPa)	1.333 224	E+00
centimeter of water (4 °C)[12]	pascal (Pa)	9.806 38	E+01
centimeter of water, conventional (cmH_2O)[12]	pascal (Pa)	**9.806 65**	**E+01**
dyne per square centimeter (dyn / cm^2)	pascal (Pa)	**1.0**	**E−01**
foot of mercury, conventional (ftHg)[12]	pascal (Pa)	4.063 666	E+04
foot of mercury, conventional (ftHg)[12]	kilopascal (kPa)	4.063 666	E+01
foot of water (39.2 °F)[12]	pascal (Pa)	2.988 98	E+03
foot of water (39.2 °F)[12]	kilopascal (kPa)	2.988 98	E+00
foot of water, conventional (ftH_2O)[12]	pascal (Pa)	2.989 067	E+03
foot of water, conventional (ftH_2O)[12]	kilopascal (kPa)	2.989 067	E+00
gram-force per square centimeter (gf / cm^2)	pascal (Pa)	**9.806 65**	**E+01**

To convert from	to	Multiply by
inch of mercury (32 °F)[12]	pascal (Pa)	3.386 38 E+03
inch of mercury (32 °F)[12]	kilopascal (kPa)	3.386 38 E+00
inch of mercury (60 °F)[12]	pascal (Pa)	3.376 85 E+03
inch of mercury (60 °F)[12]	kilopascal (kPa)	3.376 85 E+00
inch of mercury, conventional (inHg)[12]	pascal (Pa)	3.386 389 E+03
inch of mercury, conventional (inHg)[12]	kilopascal (kPa)	3.386 389 E+00
inch of water (39.2 °F)[12]	pascal (Pa)	2.490 82 E+02
inch of water (60 °F)[12]	pascal (Pa)	2.4884 E+02
inch of water, conventional (inH_2O)[12]	pascal (Pa)	2.490 889 E+02
kilogram-force per square centimeter (kgf / cm^2)	pascal (Pa)	**9.806 65 E+04**
kilogram-force per square centimeter (kgf / cm^2)	kilopascal (kPa)	**9.806 65 E+01**
kilogram-force per square meter (kgf / m^2)	pascal (Pa)	**9.806 65 E+00**
kilogram-force per square millimeter (kgf / mm^2)	pascal (Pa)	**9.806 65 E+06**
kilogram-force per square millimeter (kgf / mm^2)	megapascal (MPa)	**9.806 65 E+00**
kip per square inch (ksi) (kip / in^2)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) (kip / in^2)	kilopascal (kPa)	6.894 757 E+03
millibar (mbar)	pascal (Pa)	**1.0 E+02**
millibar (mbar)	kilopascal (kPa)	**1.0 E−01**
millimeter of mercury, conventional (mmHg)[12]	pascal (Pa)	1.333 224 E+02
millimeter of water, conventional (mmH_2O)[12]	pascal (Pa)	**9.806 65 E+00**
poundal per square foot	pascal (Pa)	1.488 164 E+00
pound-force per square foot (lbf / ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) (lbf / in^2)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) (lbf / in^2)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) (lbf / in^2)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) (lbf / in^2)	kilopascal (kPa)	6.894 757 E+00
torr (Torr)	pascal (Pa)	1.333 224 E+02

RADIOLOGY

To convert from	to	Multiply by
curie (Ci)	becquerel (Bq)	**3.7 E+10**
rad (absorbed dose) (rad)	gray (Gy)	**1.0 E−02**
rem (rem)	sievert (Sv)	**1.0 E−02**
roentgen (R)	coulomb per kilogram (C / kg)	**2.58 E−04**

SPEED (see VELOCITY)

STRESS (see PRESSURE)

TEMPERATURE

To convert from	to	Multiply by
degree Celsius (°C)	kelvin (K)	$T/\mathrm{K} = t/{}^\circ\mathrm{C} + \mathbf{273.15}$
degree centigrade[15]	degree Celsius (°C)	$t/{}^\circ\mathrm{C} \approx t/\mathrm{deg.\ cent.}$
degree Fahrenheit (°F)	degree Celsius (°C)	$t/{}^\circ\mathrm{C} = (t/{}^\circ\mathrm{F} - \mathbf{32}) / \mathbf{1.8}$
degree Fahrenheit (°F)	kelvin (K)	$T/\mathrm{K} = (t/{}^\circ\mathrm{F} + \mathbf{459.67}) / \mathbf{1.8}$
degree Rankine (°R)	kelvin (K)	$T/\mathrm{K} = (T/{}^\circ\mathrm{R}) / \mathbf{1.8}$
kelvin (K)	degree Celsius (°C)	$t/{}^\circ\mathrm{C} = T/\mathrm{K} - \mathbf{273.15}$

To convert from	to	Multiply by	
TEMPERATURE INTERVAL			
degree Celsius (°C)	kelvin (K)	**1.0**	**E+00**
degree centigrade[15]	degree Celsius (°C)	1.0	E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556	E−01
degree Fahrenheit (°F)	kelvin (K)	5.555 556	E−01
degree Rankine (°R)	kelvin (K)	5.555 556	E−01
TIME			
day (d)	second (s)	**8.64**	**E+04**
day (sidereal)	second (s)	8.616 409	E+04
hour (h)	second (s)	**3.6**	**E+03**
hour (sidereal)	second (s)	3.590 170	E+03
minute (min)	second (s)	**6.0**	**E+01**
minute (sidereal)	second (s)	5.983 617	E+01
second (sidereal)	second (s)	9.972 696	E−01
shake	second (s)	**1.0**	**E−08**
shake	nanosecond (ns)	**1.0**	**E+01**
year (365 days)	second (s)	**3.1536**	**E+07**
year (sidereal)	second (s)	3.155 815	E+07
year (tropical)	second (s)	3.155 693	E+07
TORQUE (see MOMENT OF FORCE)			
VELOCITY (includes SPEED)			
foot per hour (ft / h)	meter per second (m / s)	8.466 667	E−05
foot per minute (ft / min)	meter per second (m / s)	**5.08**	**E−03**
foot per second (ft / s)	meter per second (m / s)	**3.048**	**E−01**
inch per second (in / s)	meter per second (m / s)	**2.54**	**E−02**
kilometer per hour (km / h)	meter per second (m / s)	2.777 778	E−01
knot (nautical mile per hour)	meter per second (m / s)	5.144 444	E−01
mile per hour (mi / h)	meter per second (m / s)	**4.4704**	**E−01**
mile per hour (mi / h)	kilometer per hour (km / h)	**1.609 344**	**E+00**
mile per minute (mi / min)	meter per second (m / s)	**2.682 24**	**E+01**
mile per second (mi / s)	meter per second (m / s)	**1.609 344**	**E+03**
revolution per minute (rpm) (r / min)	radian per second (rad / s)	1.047 198	E−01
rpm (revolution per minute) (r / min)	radian per second (rad / s)	1.047 198	E−01
VISCOSITY, DYNAMIC			
centipoise (cP)	pascal second (Pa · s)	**1.0**	**E−03**
poise (P)	pascal second (Pa · s)	**1.0**	**E−01**
poundal second per square foot	pascal second (Pa · s)	1.488 164	E+00
pound-force second per square foot ($lbf \cdot s / ft^2$)	pascal second (Pa · s)	4.788 026	E+01
pound-force second per square inch ($lbf \cdot s / in^2$)	pascal second (Pa · s)	6.894 757	E+03
pound per foot hour [lb / (ft · h)]	pascal second (Pa · s)	4.133 789	E−04
pound per foot second [lb / (ft · s)]	pascal second (Pa · s)	1.488 164	E+00
rhe	reciprocal pascal second $(Pa \cdot s)^{-1}$	**1.0**	**E+01**
slug per foot second [slug / (ft · s)]	pascal second (Pa · s)	4.788 026	E+01

To convert from	to	Multiply by
VISCOSITY, KINEMATIC		
centistokes (cSt)	meter squared per second (m^2 / s)	**1.0 E−06**
square foot per second (ft^2 / s)	meter squared per second (m^2 / s)	**9.290 304 E−02**
stokes (St)	meter squared per second (m^2 / s)	**1.0 E−04**
VOLUME (includes CAPACITY)		
acre-foot (based on U.S. survey foot)[7]	cubic meter (m^3)	1.233 489 E+03
barrel [for petroleum, 42 gallons (U.S.)](bbl)	cubic meter (m^3)	1.589 873 E−01
barrel [for petroleum, 42 gallons (U.S.)](bbl)	liter (L)	1.589 873 E+02
bushel (U.S.) (bu)	cubic meter (m^3)	3.523 907 E−02
bushel (U.S.) (bu)	liter (L)	3.523 907 E+01
cord (128 ft^3)	cubic meter (m^3)	3.624 556 E+00
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E−02
cubic inch (in^3)[13]	cubic meter (m^3)	1.638 706 E−05
cubic mile (mi^3)	cubic meter (m^3)	4.168 182 E+09
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E−01
cup (U.S.)	cubic meter (m^3)	2.365 882 E−04
cup (U.S.)	liter (L)	2.365 882 E−01
cup (U.S.)	milliliter (mL)	2.365 882 E+02
fluid ounce (U.S.) (fl oz)	cubic meter (m^3)	2.957 353 E−05
fluid ounce (U.S.) (fl oz)	milliliter (mL)	2.957 353 E+01
gallon [Canadian and U.K. (Imperial)] (gal)	cubic meter (m^3)	**4.546 09 E−03**
gallon [Canadian and U.K. (Imperial)] (gal)	liter (L)	**4.546 09 E+00**
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E−03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
gill [Canadian and U.K. (Imperial)] (gi)	cubic meter (m^3)	1.420 653 E−04
gill [Canadian and U.K. (Imperial)] (gi)	liter (L)	1.420 653 E−01
gill (U.S.) (gi)	cubic meter (m^3)	1.182 941 E−04
gill (U.S.) (gi)	liter (L)	1.182 941 E−01
liter (L)[19]	cubic meter (m^3)	**1.0 E−03**
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	cubic meter (m^3)	2.841 306 E−05
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	milliliter (mL)	2.841 306 E+01
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E−05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01
peck (U.S.) (pk)	cubic meter (m^3)	8.809 768 E−03
peck (U.S.) (pk)	liter (L)	8.809 768 E+00
pint (U.S. dry) (dry pt)	cubic meter (m^3)	5.506 105 E−04
pint (U.S. dry) (dry pt)	liter (L)	5.506 105 E−01
pint (U.S. liquid) (liq pt)	cubic meter (m^3)	4.731 765 E−04
pint (U.S. liquid) (liq pt)	liter (L)	4.731 765 E−01
quart (U.S. dry) (dry qt)	cubic meter (m^3)	1.101 221 E−03
quart (U.S. dry) (dry qt)	liter (L)	1.101 221 E+00
quart (U.S. liquid) (liq qt)	cubic meter (m^3)	9.463 529 E−04
quart (U.S. liquid) (liq qt)	liter (L)	9.463 529 E−01
stere (st)	cubic meter (m^3)	**1.0 E+00**
tablespoon	cubic meter (m^3)	1.478 676 E−05
tablespoon	milliliter (mL)	1.478 676 E+01
teaspoon	cubic meter (m^3)	4.928 922 E−06
teaspoon	milliliter (mL)	4.928 922 E+00
ton, register	cubic meter (m^3)	2.831 685 E+00

To convert from	to	Multiply by	
VOLUME DIVIDED BY TIME (includes FLOW)			
cubic foot per minute (ft^3 / min)	cubic meter per second (m^3 / s)	4.719 474	E−04
cubic foot per minute (ft^3 / min)	liter per second (L / s)	4.719 474	E−01
cubic foot per second (ft^3 / s)	cubic meter per second (m^3 / s)	2.831 685	E−02
cubic inch per minute (in^3 / min)	cubic meter per second (m^3 / s)	2.731 177	E−07
cubic yard per minute (yd^3 / min)	cubic meter per second (m^3 / s)	1.274 258	E−02
gallon (U.S.) per day (gal / d)	cubic meter per second (m^3 / s)	4.381 264	E−08
gallon (U.S.) per day (gal / d)	liter per second (L / s)	4.381 264	E−05
gallon (U.S.) per minute (gpm) (gal / min	cubic meter per second (m^3 / s)	6.309 020	E−05
gallon (U.S.) per minute (gpm) (gal / min)	liter per second (L / s)	6.309 020	E−02

WORK (see ENERGY)

Appendix C. Comments on the References of Appendix D— Bibliography

C.1 Defining document for the SI: BIPM SI Brochure

The defining document for the International System of Units is the Brochure published by the International Bureau of Weights and Measures (BIPM) in French, followed by an English translation [1]. This document is revised from time to time in accordance with the decisions of the General Conference on Weights and Measures (CGPM) and the International Committee for Weights and Measures (CIPM).

C.2 United States version of defining document for the SI: NIST SP 330

The United States edition of the English translation in the BIPM SI Brochure (see Sec. C.1) is published by the National Institute of Standards and Technology as NIST Special Publication 330 [2]; it differs from the translation in the BIPM publication in the following details:

— the spelling of English-language words—for example, "meter," "liter," and "deka" are used instead of "metre," "litre," and "deca"—is in accordance with the *United States Government Printing Office Style Manual* [3], which follows *Webster's Third New International Dictionary* rather than the *Oxford Dictionary* used in many English-speaking countries. This spelling also reflects recommended United States practice (see Secs. C.1 and C.5);

— editorial notes regarding the use of the SI in the United States are added.

Inasmuch as NIST Special Publication 330 reflects the interpretation of the SI for the United States by the U.S. Secretary of Commerce (see the Preface) while at the same time highly consistent with Ref. [1] (see Sec. C.1), SP 330 is the authoritative source document on the SI for the purposes of this *Guide*.

C.3 ISO and IEC

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) both publish a series of international consensus standards to promote international uniformity in the practical use of the SI in various fields of science and technology, and in particular to standardize the symbols for various quantities and the units in which the values of these quantities are expressed. These standards are in general compatible with Ref. [1] published by the BIPM (see Sec. C.1).

Currently ISO 31 is being revised jointly by technical committees ISO TC12 and IEC TC25. The revised standards ISO/IEC 80000-1—ISO/IEC 80000-15, will supersede ISO 31-0:1992—ISO 31-13:1992 [4], which constitute a series of international consensus standards published by ISO.

IEC 60027-1—IEC 60027-4 [5] constitute a series of international consensus standards published by the IEC to promote international uniformity in the practical use of the SI in electrical technology, and in particular to standardize the symbols for various quantities used in electrotechnology and the units in which the values of these quantities are expressed. These IEC standards are also compatible with Ref. [1] published by the BIPM (see Sec. C.1), and they are coordinated with the ISO standards [4].

C.4 IEEE/ASTM SI 10

SI 10-2002 "American National Standard for Use of the International System of Units (SI): The Modern Metric System," Ref. [6], is the product of a joint effort by Institute of Electrical and Electronics Engineers (IEEE) and ASTM International (ASTM) to develop a single American National Standard Institute (ANSI) standard. It is based on the International System of Units as interpreted for use in the United States (see Secs. C.1 and C.2), and has been approved by a consensus of providers and consumers that includes interests in industrial organizations, government agencies, and scientific associations. SI 10 is

recommended as a comprehensive source of authoritative information for the practical use of the SI in the United States. (Similar documents have also been developed by other North American technical organizations; see Ref. [6], note 1.)

C.5 Federal Register Notices

Important details concerning United States customary units of measurement and the interpretation of the SI for the United States are published from time to time in the *Federal Register*; these notices have the status of official United States Government policy.

A Federal Register Notice of July 1, 1959, [7] states the values of conversion factors to be used in technical and scientific fields to obtain the values of the United States yard and pound from the SI base units for length and mass, the meter and the kilogram. These conversion factors were adopted on the basis of an agreement of English-speaking countries to reconcile small differences in the values of the inch-pound units as they were used in different parts of the world. This action did affect the value of the yard or foot used for geodetic surveys in the United States. Thus, at that time, it became necessary to recognize on a temporary basis a small difference between United States customary units of length for "international measure" and "survey measure." A Federal Register Notice of July 19, 1988, [8] announced a tentative decision not to adopt the international foot of 0.3048 meters for surveying and mapping activities in the United States. A final decision to continue the use of the survey foot indefinitely is pending the completion of an analysis of public comments on the tentative decision; this decision will also be announced in the *Federal Register*.

Even if a final decision affirms the continued use of the survey foot in surveying and mapping services of the United States, it is significant to note that the Office of Charting and Geodetic Services of the National Ocean Service in the National Oceanic and Atmospheric Administration uses the meter exclusively for the North American Datum [9]. The North American Datum of 1983, the most recent definition and adjustment of this information, was announced in a Federal Register Notice of June 14, 1989 [10].

The definitions of the international foot and yard and the corresponding survey units are also addressed in a Federal Register Notice published on February 3, 1975, [11].

A Federal Register Notice of July 27, 1968, [12] provides a list of the common customary measurement units used in commerce throughout the United States, together with the conversion factors that link them with the meter and the kilogram.

A Federal Register Notice concerning the SI [13] is a restatement of the interpretation of the International System for use in the United States, and it updates the corresponding information published in earlier notices.

A Federal Register Notice of January 2, 1991, [14] removes the voluntary aspect of the conversion to the SI for Federal agencies and provides policy direction to assist Federal agencies in their transition to the use of the metric system of measurement.

A Federal Register Notice of July 29, 1991, [15] provides Presidential authority and direction for the use of the metric system of measurement by Federal departments and agencies in their programs.

[27] The American National Standards Institute, Inc. (11 West 42nd Street, New York, NY 10036) is a private sector organization that serves as a standards coordinating body, accredits standards developers that follow procedures sanctioned by ANSI, designates as American National Standards those standards submitted for and receiving approval, serves as the United States Member Body of the International Organization for Standardization (ISO), and functions as the administrator of the United States National Committee for the International Electrotechnical Commission (IEC).

A Federal Register Notice of July 28, 1998, [16] declares that there are now only two classes of units in the International System of Units: base units and derived units. The units of these two classes form a coherent set of units and are designated by the name "SI units."

C.6 Federal Standard 376B

Federal Standard 376B [17] was developed by the Standards and Metric Practices Subcommittee of the Metrication Operating Committee, which operates under the Interagency Council on Metric Policy. Specified in the *Federal Standardization Handbook* and issued by, and available from, the General Services Administration, Washington, DC, 20406, it is the basic Federal standard that lists preferred metric units for use throughout the Federal Government. It gives guidance on the selection of metric units required to comply with PL 94-168 (see Preface) as amended by PL 100-418 (see Preface), and with Executive Order 12770 [15] (see Sec. C.5).

C.7 2006 CODATA recommended values of the fundamental constants

The set of self-consistent recommended values of the fundamental physical constants resulting from the 2006 Committee on Data for Science and Technology (CODATA) least-squares adjustment of the constants [19] can be found at the NIST website: http://physics.nist.gov/cuu/Constants/index.html. The definitive paper describing the 2006 adjustment has been accepted for publication and a preprint is available at http://physics.nist.gov/cuu/Constants/codata.pdf.

C.8 Uncertainty in measurement

Reference [20] cites two publications that describe the evaluation and expression of uncertainty in measurement based on the approach recommended by the CIPM in 1981 and which have been adopted worldwide.

Appendix D. Bibliography

[1] *Le Systéme International d'Unités (SI), The International System of Units (SI),* 8th Edition (Bur. Intl. Poids et Mesures, Sèvres, France, 2006).

Note: This publication, which is commonly called the BIPM SI Brochure, consists of the official French text followed by an English translation.

[2] *The International System of Units (SI),* Ed. by B. N. Taylor and Ambler Thompson, Natl. Inst. Stand. Technol. Spec. Publ. 330, 2008 Edition (U.S. Government Printing Office, Washington, DC, March 2008). It is available in electronic form at no charge at http://physics.nist.gov/cuu/Units/bibliography.html.

Note: This publication is the United States edition of the English translation in Ref. [1].

[3] *United States Government Printing Office Style Manual* (U.S. Government Printing Office, Washington, DC, 2000).

[4] ISO 31-0 is cited in the text in the form [4: ISO 31-0]. Currently ISO 31 is being revised jointly by ISO TC12 and IEC TC25. The revised joint standards ISO/IEC 80000-1—ISO/IEC 80000-15 will supersede ISO 31-0:1992—ISO 31-13. The completed revised joint standards published to date are included in this list, though the part numbers maybe different from the earlier designation.

Quantities and units — Part 0: *General principles,* ISO 31-0:1992.

Quantities and units — Part 2: *Periodic and related phenomena*, ISO 31-2:1992.

Quantities and units — Part 3: *Space and time,* ISO 80000-3 (2006).

Quantities and units — Part 4: *Mechanics,* ISO 80000-4 (2006).

Quantities and units — Part 4: *Heat,* ISO 31-4:1992.

Quantities and units — Part 5: *Electricity and magnetism,* ISO 31-5:1992.

Quantities and units — Part 5: *Thermodynamics*, ISO 80000-5 (2007).

Quantities and units — Part 6: *Light and related electromagnetic radiations*, ISO 31-6:1992.

Quantities and units — Part 7: *Acoustics,* ISO 31-7:1992.

Quantities and units — Part 8: *Physical chemistry and molecular physics*, ISO 31-8:1992.

Quantities and units — Part 9: *Atomic and nuclear physics,* ISO 31-9:1992.

Quantities and units — Part 10: *Nuclear reactions and ionizing radiations*, ISO 31-10:1992.

Quantities and units — Part 11: *Mathematical signs and symbols for use in physical sciences and technology*, ISO 31-11:1992.

Quantities and units — Part 12: *Characteristic numbers,* ISO 31-12:1992.

Quantities and units — Part 13: *Solid state physics,* ISO 31-13:1992.

Note: ISO 31-0:1992— ISO 31-13:1992 and ISO 1000:1992 are reprinted in the ISO Standards Handbook *Quantities and units* (International Organization for Standardization, Geneva, Switzerland, 1993).

[5] The following four standards, which are cited in the text in the form [IEC 60027-X], are published by the International Electrotechnical Commission (IEC), Geneva, Switzerland.

Letter symbols to be used in electrical technology, Part 1: *General,* IEC 60027-1 (1992).

Letter symbols to be used in electrical technology, Part 2: *Telecommunications and electronics,* IEC 60027-2 (2005).

Note: As pointed out in Sec. 4.3.,the SI prefixes refer strictly to powers of 10. They should not be used to indicate powers of 2 (for example, one kilobit represents 1000 bits and not 1024 bits). The IEC has adopted prefixes for binary powers in the above standard. The names and symbols for the prefixes corresponding to 2^{10}, 2^{20}, 2^{30}, 2^{40}, 2^{50}, and 2^{60} are, respectively: kibi, Ki; mebi, Mi; gibi, Gi; tebi, Ti; pebi, Pi; and exbi, Ei. Thus, for example, one kibibyte would be written: 1 KiB = 2^{10} B = 1024 B, where B denotes a byte. Although these prefixes are not part of the SI, they should be used in the field of information technology to avoid the incorrect usage of the SI prefixes.

Letter symbols to be used in electrical technology, Part 3: *Logarithmic and related quantities and their units,* IEC 60027-3 (2003).

Letter symbols to be used in electrical technology, Part 4: R*otating electrical machines, IEC 60027-4 (2006).*

[6] SI 10-2002 IEEE/ASTM Standard for Use of the International System of Units (SI): The Modern Metric System. A joint ASTM-IEEE effort to develop a single ANSI standard.

Notes:

1. A number of similar standards for metric practice are published by technical organizations. They include:

   Rules for SAE Use of SI (Metric) Units, TSB003 MAY 1999 (Society of Automotive Engineers, Warrendale, PA, May 1999).

2. The Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, Ontario, Canada, L4W 5N6, publishes CAN/CSA-Z234.1-00 (R2006), Canadian Metric Practice Guide, a Canadian National Standard.

3. The application of the SI to physical chemistry is discussed in *Quantities, Units and Symbols in Physical Chemistry*, Third Edition (International Union of Pure and Applied Chemistry, RSC Publications, Cambridge, 2007).

[7] *Federal Register*, Vol. 24, No. 128, p. 5348, July 1, 1959.

[8] *Federal Register*, Vol. 53, No. 138, p. 27213, July 19, 1988.

[9] *Federal Register*, Vol. 42, No. 57, p. 8847, March 24, 1977.

[10] *Federal Register*, Vol. 54, No. 113, p. 25318, June 14, 1989.

[11] *Federal Register*, Vol. 40, No. 23, p. 5954, February 3, 1975.

[12] *Federal Register*, Vol. 33, No. 146, p. 10755, July 27, 1968.

[13] *Federal Register*, Vol. 55, No. 245, p. 52242, December 20, 1990.

[14] *Federal Register*, Vol. 56, No. 1, p. 160, January 2, 1991.

[15] *Federal Register*, Vol. 56, No. 145, p. 35801, July 29, 1991.

[16] *Federal Register*, Vol. 63, No. 144, p. 40334, July 28, 1998.

[17] *Preferred Metric Units for General Use by the Federal Government*, Federal Standard 376B (General Services Administration, Washington, DC, 1993).

[18] *Quantities and Units in Radiation Protection Dosimetry,* ICRU Report 51, 1993 (International Commission on Radiation Units and Measurements, 7910 Woodmont Avenue, Bethesda, MD, 20814).

[19] Values for the 2006 adjustment of the fundamental physical constants can be found at the NIST website (http://physics.nist.gov/cuu/Constants/index.html). The definitive paper describing the 2006 adjustment has been accepted for publication and a preprint can be found at http://physics.nist.gov/cuu/Constants/codata.pdf.

Note: For a detailed description of the previous 2002 adjustment of the values for the constants see P. J. Mohr and B. N. Taylor, Reviews of Modern Physics, Vol. 77, No. 1, pp. 1-107, 2005.

[20] The term standard uncertainty used in the footnotes to Table 7 of this *Guide*, and the related terms expanded uncertainty and relative expanded uncertainty used in some of the examples of Sec. 7.10.3, are discussed in ISO, *Guide to the Expression of Uncertainty in Measurement* (International Organization for Standardization, Geneva, Switzerland, 1995); and in B. N. Taylor and C. E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results,* Natl. Inst. Stand. Technol. Spec. Publ. 1297, 1994 Edition (U.S. Government Printing Office, Washington, DC, September 1994).

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SI COHERENT DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS

(Explanation of Graphic on Back Cover)

Derived units are defined as products of powers of the base units. When the product of powers includes no numerical factor other than one, the derived units are called "coherent derived" units. The base and coherent derived units of the SI form a coherent set, designated the set of "coherent SI units." The word coherent is used here in the following sense: when coherent units are used, equations between the numerical values of quantities take exactly the same form as the equations between the quantities themselves. Thus, if only units from a coherent set are used, conversion factors between units are never required.

The diagram on the back page of SP811 shows graphically how the 22 SI coherent derived units with special names and symbols are related to the seven SI base units.

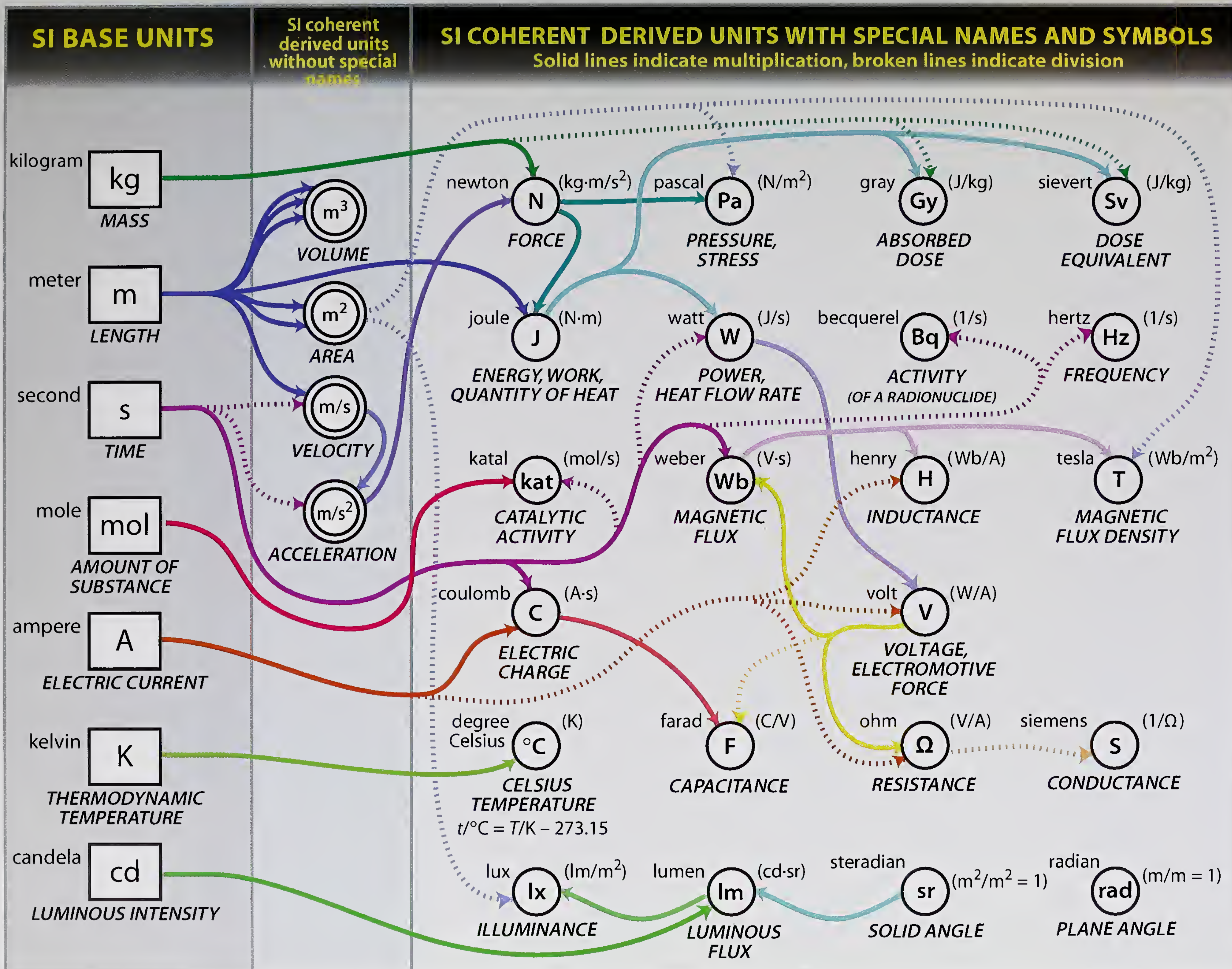
1. In the first column, the symbols of the SI base units are shown in rectangles, with the name of the unit shown toward the upper left of the rectangle and the name of the associated base quantity shown in italic type below the rectangle.

2. In the second column are shown those additional coherent derived units without special names that are necessary for the derivation of the coherent derived units with special names [the cubic meter (m^3) excepted]. In the diagram, the derivation of each coherent derived unit is indicated by arrows that bring in units in the numerator (solid lines) and units in the denominator (broken lines), as appropriate.

3. In the third column the symbols of the 22 SI coherent derived units with special names are shown in solid circles, with the name of the unit shown toward the upper left of the circle, the name of the associated derived quantity shown in italic type below the circle, and an expression for the derived unit in terms of other units shown toward the upper right in parenthesis.

Two SI coherent derived units with special names and symbols, the radian, symbol rad, and the steradian, symbol sr (bottom-right of the third column of the diagram), are shown without any connections to SI base units – either direct or through other SI derived units. The reason is that in the SI, the quantities plane angle and solid angle are defined in such a way that their dimension is one – they are so-called dimensionless quantities. This means that the coherent SI derived unit for each of these quantities is the number one, symbol 1. That is, because plane angle is expressed as the ratio of two lengths, and solid angle as the ratio of an area and the square of a length, the SI coherent derived unit for plane angle is m/m = 1, and the SI coherent derived unit for solid angle is $m^2/m^2 = 1$. To aid understanding, the special name "radian" with symbol rad is given to the number 1 for use in expressing values of plane angle; and the special name "steradian" with symbol sr is given to the number 1 for use in expressing values of solid angle. However, one has the option of using or not using these names and symbols in expressions for other SI derived units, as is convenient.

The unit "degree Celsius," which is equal in magnitude to the unit "kelvin," is used to express Celsius temperature *t*. In this case, "degree Celsius" is a special name used in place of "kelvin." This equality is indicated in the diagram by the symbol K in parenthesis toward the upper right of the °C circle. The equation below "*CELSIUS TEMPERATURE*" relates Celsius temperature *t* to thermodynamic temperature *T*. An interval or difference in temperature may be expressed equivalently in either kelvins or in degrees Celsius.



SI BASE UNITS
SI coherent derived units without special names
SI COHERENT DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS
Solid lines indicate multiplication, broken lines indicate division
kilogram kg MASS
meter m LENGTH
second s TIME
mole mol AMOUNT OF SUBSTANCE
ampere A ELECTRIC CURRENT
kelvin K THERMODYNAMIC TEMPERATURE
candela cd LUMINOUS INTENSITY
m³ VOLUME
m² AREA
m/s VELOCITY
m/s² ACCELERATION
newton N (kg·m/s²) FORCE
pascal Pa (N/m²) PRESSURE, STRESS
gray Gy (J/kg) ABSORBED DOSE
sievert Sv (J/kg) DOSE EQUIVALENT
joule J (N·m) ENERGY, WORK, QUANTITY OF HEAT
watt W (J/s) POWER, HEAT FLOW RATE
becquerel Bq (1/s) ACTIVITY (OF A RADIONUCLIDE)
hertz Hz (1/s) FREQUENCY
katal kat (mol/s) CATALYTIC ACTIVITY
weber Wb (V·s) MAGNETIC FLUX
henry H (Wb/A) INDUCTANCE
tesla T (Wb/m²) MAGNETIC FLUX DENSITY
coulomb C (A·s) ELECTRIC CHARGE
volt V (W/A) VOLTAGE, ELECTROMOTIVE FORCE
degree Celsius °C (K) CELSIUS TEMPERATURE
t/°C = T/K – 273.15
farad F (C/V) CAPACITANCE
ohm Ω (V/A) RESISTANCE
siemens S (1/Ω) CONDUCTANCE
lux lx (lm/m²) ILLUMINANCE
lumen lm (cd·sr) LUMINOUS FLUX
steradian sr (m²/m² = 1) SOLID ANGLE
radian rad (m/m = 1) PLANE ANGLE